A Nuffield Farming Scholarships Trust
Report

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Precision Agriculture:
how to realise the full potential

Andrew Williamson

July 2014

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A Nuffield (UK) Farming Scholarships Trust Report

Date of report: July 2014

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	Precision Agriculture : how to realise the full potential
Scholar	Andrew Williamson
Sponsor	NFU Mutual Charitable Trust
Objectives of Study Tour	Investigate how Precision Agriculture can: • increase production • manage resources more efficiently • assist the development of new technology Interpretation and management of Data to gain the greatest benefit
Countries Visited	Canada, USA, Mexico, Germany, New Zealand, Australia and Brazil
Findings	• UK agriculture is perfectly suited to take full advantage of Precision agriculture. • Precision Agriculture will increase production using variable rate application prescriptions, and improve efficiency through better machine control • Precision agriculture and advanced machine control will be critical to fulfil the potential of scientific advances in crop breeding programmes. • Data analysis is key to unlocking the full potential of variable rate technology. It has to be good enough to determine the cause of the variation, and not just measure the variation. • Data is king - how it is collected, interpreted, utilised and who owns it. Data management has to be simple, intuitive and freely available across all devices, from in cab controllers to a smartphone in a farmer's pocket.

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DISCLAIMER

The opinions expressed in this report are my own and not necessarily those of the Nuffield Farming Scholarships Trust, or of my sponsor, or of any other sponsoring body.

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1. Introduction

Me, Andrew Williamson

Following a long line of farmers from both my parents' families I always knew deep down that I would become one myself. Having said that, at the tender age of 18 I was unsure, so with the knowledge that the opportunity to farm in the future would be available, I decided to go to university. After completing a BSc Hons in Chemistry at the University of Bristol, it was decision time again. Stay on in education, go to London and get a job along with most of my friends or go home to farm? I had reached my level academically, had no desire to get a city job and still wasn't ready to return home to farm. With my new independence, an around-the-world plane ticket was purchased and a 2 year trip travelling and working on farms - where else - ensued.

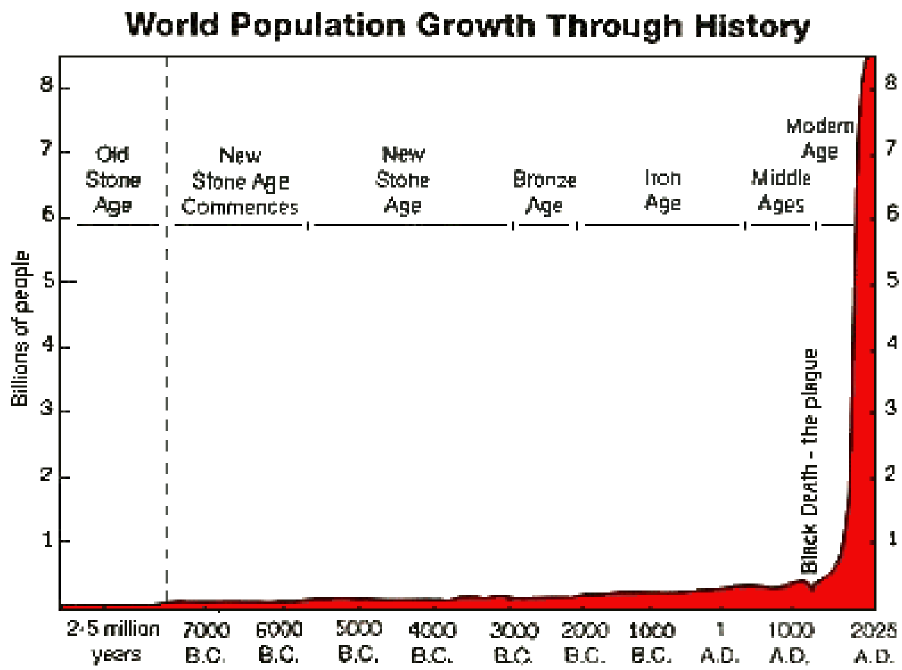
One evening, in a backpacker's hostel in Sydney, Australia, on the phone to my parents I realised that I wanted to come home to farm. This was an early indication to me how distance and time away from your day to day life can clarify your choices, and was later to become one of the attractions of a Nuffield Farming Scholarship.

I am now married to Caroline and we have 3 wonderful children James, Hannah, and Harriet, who was born during my Scholarship year. We live near Bridgnorth, in south Shropshire, where I am the managing partner of our family farming partnership. We farm 900 acres of predominately combinable crops, wheat, barley, oilseed rape (canola) and oats. Alongside this we let out some permanent pasture for sheep grazing. All the land we manage is covered by a higher level stewardship (HLS) scheme, the aim of which is to increase the level of farmland birds by improving habitat and providing alternative feed sources. As part of our HLS scheme we have allowed permissive access to 6km of bridleways, to encourage the public to see what we do – for I believe it is up to us as land managers to engage with people from outside agriculture to inform them what, when, how and why we do what we do.

2 - Background to my study

As farmers I believe the greatest challenge we face globally is how to feed a growing population. World population is increasing year on year, by 1.1% or 80 million, even though birth rates are decreasing. The current world population of 7.2 bn is predicted to reach 9.5 bn by 2050. If population continues to grow at this rate, by the end of this century there will be four times as many people to feed compared to 1950.

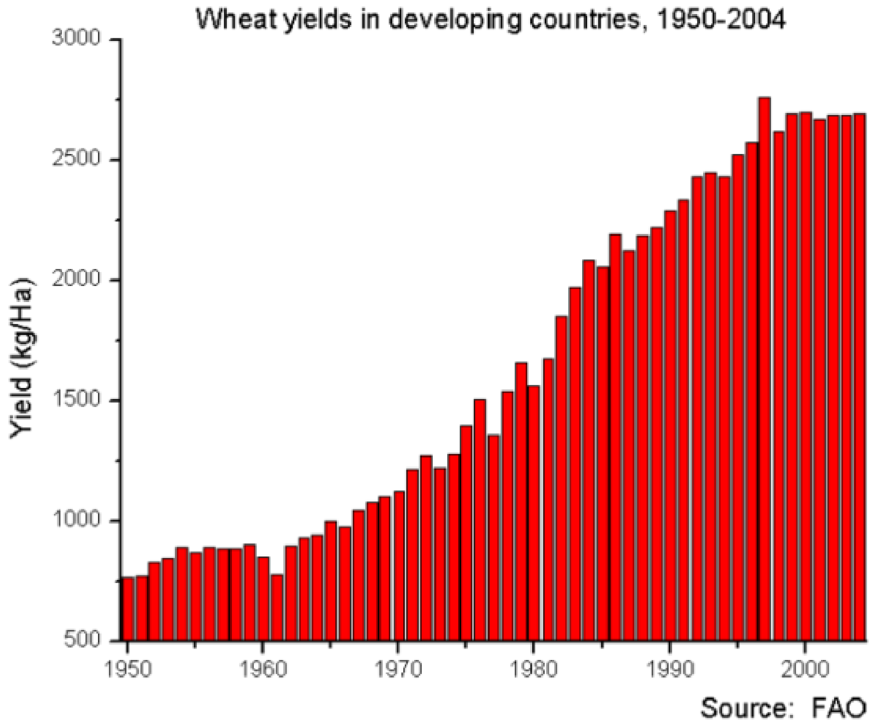
If you consider it was in the 1950s that Dr. Norman Borlaug, the "Father of the Green Revolution", was credited with saving over a billion people from starvation through the development of high-yielding varieties of cereal grains, expansion of irrigation infrastructure, modernisation of management techniques, distribution of hybridized seeds, synthetic fertilisers, and pesticides to farmers - it demonstrates the gravity of the challenge ahead.



World population: toward the next century. *Population reference Bureau, 1984*

The graph above clearly shows the extent of the exponential population growth. The impact of the green revolution on wheat yields is obvious, but the rapid improvement has started to plateau. (*See graph on next page).* Why is this and how can it be changed?

Added to this the land base to produce the food is declining, due to urbanisation, poor agricultural practice and erosion. Therefore we are going to have to produce more from less. This is where precision farming can have a major impact on the way we produce food.



- I want to investigate how precision farming techniques can be fully utilised to make more efficient use of expensive inputs, such as fertiliser, pesticides and water. This could be through intelligent soil sampling to gain a better understanding of what is available to the crop, along with historical data.
- I want to find out more about real time canopy sensing technology. We currently use a remote nitrogen sensor, but what else could we measure and record?

We are going to have to produce more from less. This is where precision farming can have a major impact on the way we produce food.

- I also want to research how precision farming can be employed to deliver new technological advances, as they become more widely available.
- Also, how do we best manage all the data collected and ensure that it is accurate and meaningful?

3 - My study tour

We use several precision farming techniques at home, including yield mapping, variable rate fertiliser and seed, auto sectional control and GPS guidance. I visited some businesses in the UK before travelling overseas to be able to make comparisons during my travels. Below is an outline of where I went and what I hoped to discover.

Country	When	Why
UK	2013 & 2014	I visited SOYL, one of the major PA (Precision Agriculture) providers in the UK since 1993. Also Precision Decisions, set up by Clive Blacker after completing a Nuffield Scholarship in 2004, and the supplier of the Yara N-sensor in the UK. Intelligent Precision Farming, working with zone maps and soil brightness imagery.
Canada	March & June 2013	I visited Canada in March as part of my CSC (Contemporary Scholars Conference) and then returned in June to find out how well Canadian farmers were adopting PA, with a particular interest in variable rate applications and machine control.
USA	July 2013	As one of the main cropping regions of the world I wanted to see how the USA compared to the UK in its uptake of PA, was it leading the world? What do machinery manufacturers think is the future of PA? How is data handled on a large scale? Are compatibility issues as big a problem as they are in the UK?
Mexico	July 2013	I visited Cimmyt, International Maize and Wheat improvement centre, where Dr. Norman Borlaug, pioneered the breeding of semi dwarf wheat varieties that we use today and started the green revolution. How can PA assist in the breeding of new varieties?
Germany	November 2013	I visited Agritechnica, the largest agricultural exhibition, in Europe and Yara's fertiliser research station.
New Zealand	January 2014	I wanted to visit New Zealand primarily because it has a similar climate and growing season to the UK. Holds the current wheat yield record of 15.66T/ha or double the average UK wheat yield. How are they achieving those yields? Does PA have an input?
Australia	February 2014	How are Australian farmers using PA to help them farm in a very challenging environment, without the support of any subsidies? Particularly, looking at how traffic and water are managed.
Brazil	February 2014	How is PA being adopted in one of the fastest developing countries in the agricultural world? Also, because I had never been before and what better opportunity than during a Nuffield Farming Scholarship?

4. What is Precision Agriculture?

Precision Agriculture (PA) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. Crop variability typically has both a spatial and temporal component which makes statistical/computational treatments quite involved.** It is only through the adoption of GPS (Global Positioning System) (*see Appendix 1 for more details*) control that this has become possible for farmers. GPS has given farmers the ability to locate their precise position in a field which allows them to measure and record geo-referenced information. This information can then be used in the future to influence management decisions.

PA can be broken down into three distinct but interrelated components:

- Machine Control
- Variable Rate Application (VRA)
- Data Collection and Interpretation

Machine control uses GPS to either steer the vehicle on a predetermined path, such as auto steer, or control when a machine switches on or off according to its spatial position, commonly referred to as sectional control. Both of these topics will be discussed later in greater detail.

VRA is the implementation of site specific treatments across a field, where a field is either divided into management zones or a real time sensor is used. The management zones can be setup in various ways relating to which variable has been previously recorded: for example soil analysis, soil conductivity, yield or satellite imagery. Real time sensors can be used to measure visible crop variations and the input adjusted according to the sensor reading, based on a known algorithm for that particular parameter.

The collection of geo-referenced spatial data is the easy part; yield data from harvesters has been collected for over 20 years, but beyond looking at the pretty pictures produced, how do we accurately interpret the data and utilise it to improve future management decisions?

All the methods mentioned above help farmers to manage inputs in a more intelligent, efficient and environmentally sensitive way. They introduce virtual boundaries within a field, and allow fields within fields to be managed. It is in effect turning back time to the way our predecessors farmed before the post-Second World War drive to increase production through the wide adoption of mechanisation.

It is in effect turning back time to the way our predecessors farmed before the post-Second World War drive to increase production through the wide adoption of mechanisation.

***For a fuller explanation of these terms see 1st paragraph of Chapter 12 on page 34*

5 - Machine control – the possibilities

As outlined earlier, machine control is the utilisation of GPS guidance to control where a tractor or machine is located spatially. This control allows many other operations to become possible, each of which I will describe in more detail in the following chapters.

5.1 - CTF – controlled traffic farming

By using the RTK guidance it is possible to control the areas in a field which are driven on. This is only possible due to the accuracy and repeatability of RTK. The basic principle involves keeping all machines on the same track width, normally 3m centre-to-centre and also having the larger implement width a multiple of the smaller ones.

Common example: 12m Drill, combine and cultivator, used with a 36m Sprayer – 3:1 ratio

Whereas the traditional approach of random traffic can cause 140% (due to several uses of the same tracks) of the field to be driven over, it is possible with CTF to achieve as low as 18% of the field to be driven on. There are many benefits, such as reduced compaction, increased water infiltration, improved water holding capacity, higher efficiency, all of which will increase yields.

I was shown a clear indication of the improved rooting of an oilseed rape plant, grown using CTF techniques, whilst visiting Canadian Nuffield Scholar, Steve Larocque, in Alberta.

Oilseed Rape roots CTF (on left) compared to Random Traffic (on right)

Each plant in the picture above was treated in exactly the same way with the exception of traffic. The rooting of the CTF plants is vastly superior to the random traffic plants due to the improved soil structure.

CTF has been discussed very extensively and thoroughly by a previous 2010 UK Nuffield Farming Scholar James Peck. For a more in depth analysis I would refer you to his report.

5.2 - Inter-row seeding

Inter-row seeding is another development of RTK guidance and can be easily implemented in a CTF system, particularly if a no-till or direct drilling policy is in place.

Inter-row seeding started as a way to overcome residue management issues in a direct drilling situation, where high levels of residue were blocking the seed drill. By moving the seed coulter between the previous crop stubble rows, this was reduced.

Soya beans planted inter row in Alberta

Wheat planted inter row in Alberta

There are 2 different ways to achieve inter-row seeding depending on your attitude to CTF and wheeling management. The simplest way is to shift the A-B line half the distance between the coulters on the drill to one side, and everything will move across. Alternatively if you want to continue to use the same A-B lines, the drill has to be offset relative to the tractor. This can be achieved by 2 different approaches, either the pull point of the drill is offset *or* a hydraulic ram is fitted to the drawbar of the drill.

Offset pull point on a drill drawbar

Hydraulic rams fitted to a drill drawbar

The advantage of using a hydraulic ram over moving the pull point is the ability to work in rows as the drill can be offset to either side of the tractor.

5.3 - Sectional control

Sectional control is the ability to split a machine into different sections, which can be controlled independently of each other. When sectional control is linked to a GPS signal, the machine knows its current location and where it has been, referred to as coverage. These two parameters prevent the machine overlapping and double-dosing areas and also leaving areas untreated, resulting in improved efficiency and better stewardship of application.

Sectional control is more suited to wide implements, hence in the UK is mostly seen on sprayers and fertiliser spreaders, with sprayers being the most popular. It is normal to see a 4% reduction in inputs when sectional control is adopted. In other countries where seed drills can be up to 24 m wide sectional control is being employed. The main reason to use sectional control is to reduce overlap of inputs, which leads to increased cost and also reduced yields in some cases.

When sectional control is used on row planters the advantages are increased dramatically, as each row can be controlled individually. Each row also effectively has its own rate controller. This means that each row can be treated in isolation if needed, turned on and off independently of each other, and also apply a different rate.

Sectional control used to plant soya beans in Iowa, USA

Choosing the correct corn hybrid is one of the most important decisions a grower can make each and every year.

New technological advances in corn planters continue to be unveiled. Among the most interesting recent developments are multi-hybrid planters, which would allow farmers to switch between multiple hybrids across a field automatically when planting, where each hybrid has different characteristics. Raven Industries and Kinze Manufacturing, Inc. are collaborating on the control system for a new 4900 series multi-hybrid planter being tested with select North American farmers in the spring of 2014. This planter will be the first to offer farmers this capability as a factory-installed option. Multi-hybrid technology allows corn planting to include precision hybrid placement. Choosing the correct corn hybrid is one of the most important decisions a grower can make each and every year. Multi-hybrid testing has shown significant yield gains and profitability by changing the corn hybrid planted on-the-go based upon varying degrees of yield potential throughout a field. Instead of farmers selecting an average hybrid for use across the entire field, different hybrids can be selected and automatically planted to suit different field management zones.

Kinze said farmers can utilise a "racehorse" seed variety in areas of high productive soils and more of a "workhorse" variety in less productive areas. In fields with poor drainage, a variety which can handle moisture could be planted in these areas while a more productive variety could be used in field locations with higher elevation. "*The electric multi-hybrid planter will allow farmers to maximize yield in every part of their field, and not have to make compromises,*" said Rhett Schildroth, senior product manager at Kinze Manufacturing. "*The yield gains in our trials varied from 2 bushels per acre to more than 10 bushels per acre (0.12 – 0.62 T/ha) by utilising multi-hybrid planting.*"

The multi-hybrid concept planter has new row units that incorporate two meters for every row. This meter feeds a single seed tube so the row unit gauge wheels, openers and closing wheels are identical to a standard Kinze 4000 series row unit. By eliminating the drive chain and clutch, Kinze were able to orient the meters close together so that they feed a single seed tube.

5.4 – Down force control

Whilst in Indiana, USA, I visited Mark Waibel, Solid Rock Farms, near Remington. Mark farms with his father and uncle, cropping 1000 acres of corn (maize). Alongside the farming business, they are also dealers for Precision Planting products, which replace OEM (original equipment manufacturers) controllers with their own.

Myself and Mark Waibel

One of the concepts that Precision Planting are working on is down force control. The aim is to get an even seed depth in variable soils and conditions, by avoiding shallow-planted seeds and root compaction. Simply put, you pave the way for higher yields. This concept is called DeltaForce™. In every metre on every pass, in each individual row, it monitors row unit weight and ground contact, then instantly and automatically adjusts to maintain the depth you set. In a four year study, managing down force improved yield on average 8.7 bushels/ac (0.53T/ha), (*Source: Becks Practical Farm Research. 2008-2012).* DeltaForce works with a 20/20 SeedSense® planter controller replacing the springs or air bags on your planter. It includes hydraulic cylinders, plus a weigh pin that sends data to SeedSense which, in turn, controls the cylinders, down force and ultimately seed placement.

Hydraulic down force control

5.5 - Implement steer

It seems that the more precision and accuracy farmers have, the more they demand. Having got self-steer tractors and RTK guidance, the operator has more time to notice that the following implement is not following as accurately as first thought. In the drive for more precision and the next piece of technology, farmers are starting to fit a separate GPS receiver to the implement, which then controls the path of the implement independently of the tractor.

Wade and Clay Mitchell

I visited "The Mitchell Farm" in Iowa, USA, where Clay Mitchell and his father Wade grow corn, seed corn and soya beans. They have been heavily involved with PA for over 20 years. Wade worked for John Deere for over 30 years before retiring from full time employment, but is still involved with John Deere's advanced engineering department. Clay has a biomedical engineering degree from Harvard University, so is not your average farmer. The Mitchells use implement steer on several implements. Some have a hydraulic ram on the drawbar, others steer the wheels of the implement and the planters do both. The planters used both techniques because it was found that, even if the drawbar was adjusted, the coulters were still off line due to the distance they are from the pivot point of the tractor and planter. This is active implement steer, as the implement steers independently to the tractor.

In northern Alabama, USA I visited Mark Hamilton who farms 5000 acres near Decatur growing corn, cotton, soya beans and winter wheat. Soya beans were planted so soon after the wheat harvest that sometimes the planter would be in the same field as the combines. This was the case the day I visited. Mark uses a passive implement steering system on the planter. The receiver on the planter is linked to the receiver on the tractor, and will correct the tractor's position and steer it off its own A-B line until the planter is on track.

Passive implement steeringsystem with a GPS receiver on the planter

As mentioned before, the amount of control on a machine is only limited by the farmer's imagination and desire for precision. James Hassall, an Australian Nuffield Scholar from Gilgandra, NSW, has taken implement steer to the extreme to fit in with his CTF system and inter-row planting, (*diagram below*). The tractor stays on the permanent CTF wheelings, and the seeding bar has its own receiver (R2) which can be moved from side to side by a linear motor to give the correct offset to maintain the inter-row seed placement, irrespective to which way the operator is working across the field.

You would think this would be the perfect solution, but not for James. As the seed cart is towed by the seeding bar its wheel track is not directly behind the tractor wheel track. James has fitted 2 discs to the back of the seeding bar to fix its path and act as a pivot point for the seed cart which is brought back in line by a hydraulic ram on the seed cart drawbar. This ram is linked to the ram on the seeding bar drawbar to make sure it moves back in line.

Most of the modifications were done on the farm by James, which is a true example of the innovative and adaptive attitude of Australian farmers.

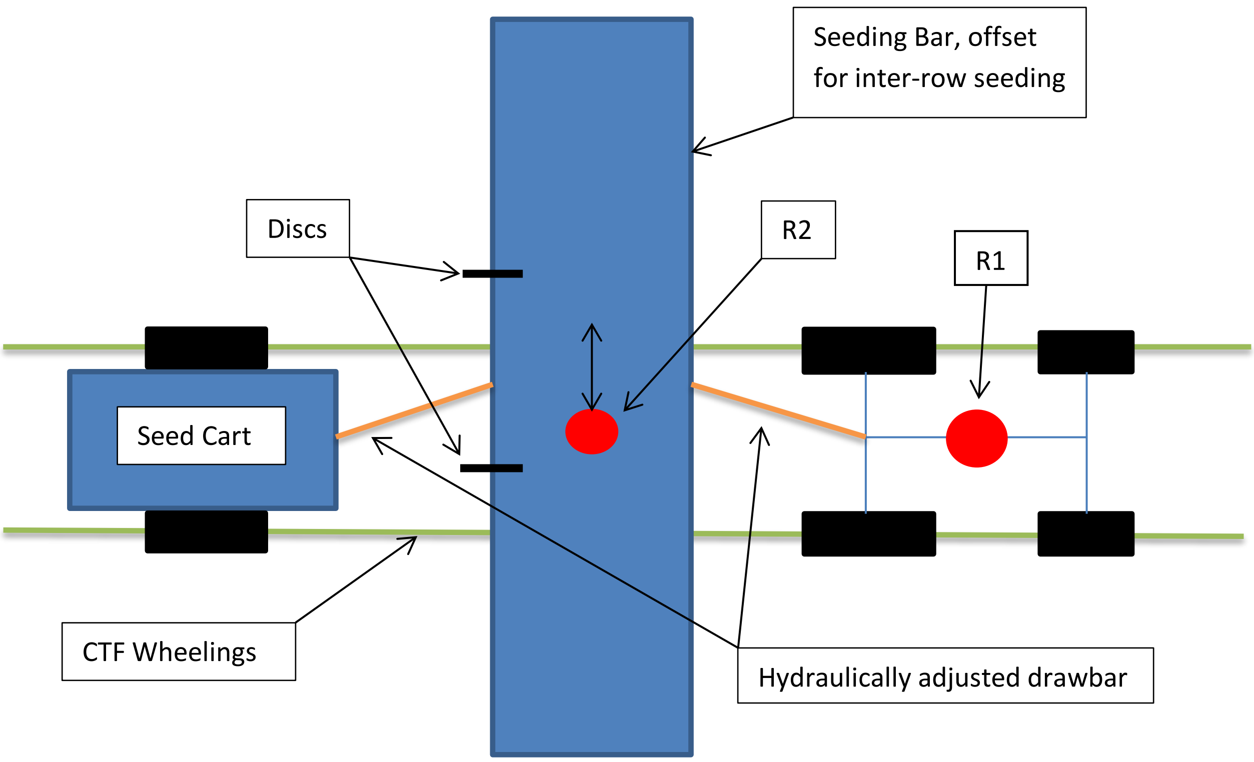


Diagram of James Hassall's implement steer seeding bar

5.6 - Sprayer control and pulse width modulation

As previously mentioned the most popular use of auto section control on UK farms is on boom sprayers. This is due to their wider working widths and ease of adaption. Is auto section control the end or are there other possibilities?

I first encountered pulse width modulation (PWM) when visiting Tom Wolf, a spray application specialist in Saskatoon, Saskatchewan, Canada. To enable PWM, the nozzle body solenoids have to be replaced with electric solenoids, which then pulse the nozzle on and off 10 times per second. This allows the application rate to change by varying the amount of time per second that the nozzle is either open or closed, which means that the application rate and pressure can be held constant as the forward speed is varied. This maintains a uniform droplet size, increases efficacy and reduces drift. It is claimed that by using individual nozzle control you can reduce overlap by 6% over standard automatic section control. This is a large saving, and when added to the better droplet size control makes it very interesting.

Tom and I discussed the concept of "turn compensation" and how PWM coupled with individual nozzle control makes it a reality. Turn compensation is when the application rate can be varied along a sprayer boom from nozzle to nozzle to allow for the fact that the further out the nozzle is the faster it is going over the crop as the sprayer turns. As the total application rate along the boom is fixed by the rate controller, turn compensation relies on the mechanics of a boom sprayer, in so far as if one end is speeding up the opposite end will be slowing down, due to the fact it is turning around a central position.

In Illinois, USA, I meet up with Dave Annis from Capstan Ag systems, the company that patented PWM technology. Using probably the most sophisticated Polaris ranger mounted sprayer you will see, Dave demonstrated the capabilities of PWM. It was clear to see how PWM reduced drift and maintained a constant spray pattern regardless of forward speed.

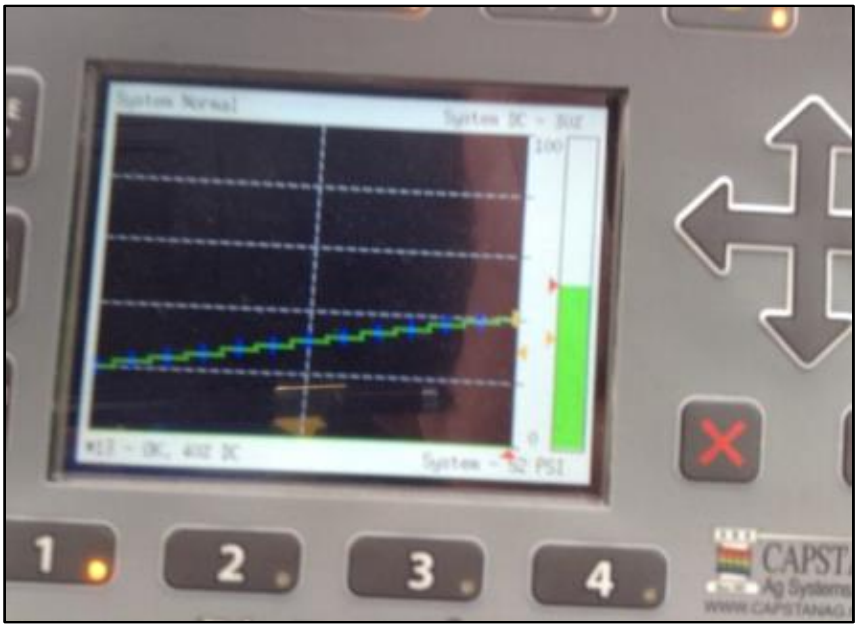
Dave with the most sophisticated Polaris Ranger mounted sprayer

See two more pictures of turn compensation and PWM on next page.

5.7 - Autonomous tractor

Autonomous machines are a massive topic in their own right, and were covered extensively by James Szabo, 2012 UK Nuffield Farming Scholar in his report. However PA has a major part in the development of autonomous machines, in their control and their artificial intelligence.

Fendt tractors have developed a leader-follower system, where one operator can drive one tractor, and operate another identical tractor remotely. Both machines have to be carrying out the same task. John Deere has a system called Machine Sync, used for unloading a combine. Both machines



Turn compensation in action

Reduced drift of PWM (near side of boom) compared to a traditional flat fan nozzle (far side of boom) at the same rate and pressure.

require a driver, and GPS guidance, but when the tractor and grain cart get within a certain range of the combine, the combine operator can take control of the tractor, and sync its movement with the combine.

A true driverless tractor has been developed by Kinze manufacturing, Iowa, USA. Kinze have developed an autonomous tractor to pull one of their grain carts, and had three under evaluation in 2013. The combine operator controls the tractor which is fitted with GPS steering and LIDAR (light detection and ranging) technology. (*See photo on next page*). LIDAR sends out millions of points of light every second and measures the time it takes that light to hit something and bounce back. With this data it can essentially "see" a three-dimensional image of objects around it. The combine operator can instruct the tractor and grain cart to do four things: Stop, Follow, Unload and Return to Base. The tractor starts in a designated staging area. When the combine is full the driver can call the tractor to drive alongside and unload. After unloading it will either come to a controlled stop, or continue to follow the combine before unloading again. Once the grain cart is full the combine driver can send it back to the staging area. To empty the grain cart, the truck driver folds down the steps to get into the tractor cab, which deactivates the automation, and then drives it exactly the same as a normal tractor. The tractor will only go where the combine has already harvested, to prevent crop damage, and will take the most direct route to get to the combine at the moment, but could be setup for CTF in the future. If the tractor detects an obstacle that it can't drive around it will come to a stop. The system is a very good idea, and would genuinely reduce the labour requirement at harvest, but is not currently commercially available.

To see it in action follow the link: https://www.youtube.com/watch?v=nj_EYZeSkhM (July 2014)

A LIDAR image

6 - Variable rate application – collecting data

Variable rate application (VRA) is the practice of applying different amounts of an input on different parts of a field due to a measured variation. The variation could have been recorded historically by soil sampling or in real time with an optical sensor. VRA allows virtual boundaries to be set up in a field, and fields within fields to be managed differently.

__The five R's of Variable rate__

-Right Product

-Right Place

-Right Time

-Right Rate

-Right Reason

All inputs have the potential to be applied using VRA, but the difficulty is deciding what, where, when, how much and why. During my travels I saw many examples of farmers using VRA to improve the efficiency of inputs including fertiliser, seed, pesticides, water and lime. In all cases the overall aim was to drive up yields and get closer to the yield potential of an area. Before a VRA can be actioned the variable in question has to be measured and spatially fixed. There are several ways to do this, outlined below, and which method is used will depend on what the variable is.

6.1 - Grid sampling

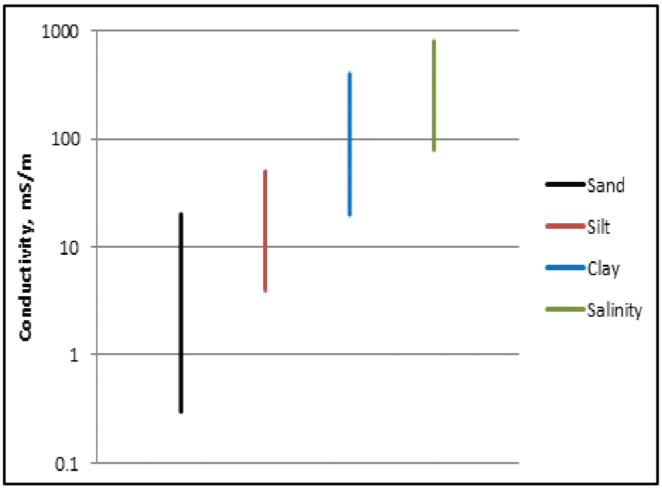
The most common way is to divide a field into 1ha grids then take a soil sample in each grid. Then by using a VRA plan only apply the correct amount of input required in each grid rather than an average across the field. This method has been shown to reduce inputs greatly without an impact on yield.

6.2 - Yield maps

Yield maps can be converted into offtake maps of a particular nutrient, such as Potash or Phosphate, which can be replaced accordingly. An advantage of offtake maps over grid maps is that a sample is taken much more often, resulting in a higher resolution dataset. Yield maps are also very good for highlighting areas which are underperforming.

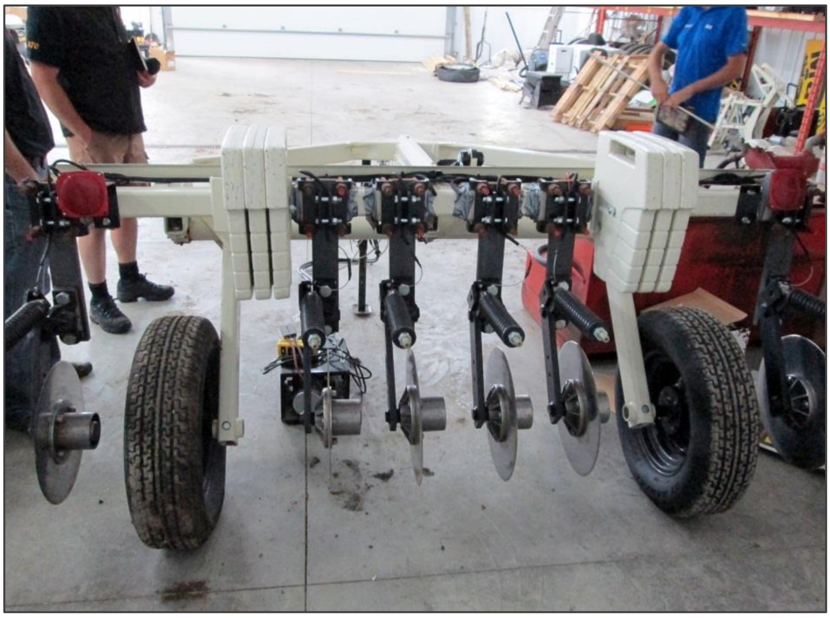
6.3 - Electrical conductivity

Soil electrical conductivity (EC) is an indirect measurement that correlates very well with several soil physical and chemical properties. Electrical conductivity is the ability of a material to conduct (transmit) an electrical current and it is commonly expressed in units of milliSiemens per meter (mS/m). Alternatively, electrical conductivity measurements can be expressed in deciSiemens per meter (dS/m), which is 100 times greater than milliSiemens per meter. Different soil types will typically have different EC readings, *see graph opposite.*



Electrical conductivity of different soil materials

Therefore it is relatively easy to convert an EC map to a soil type map and create management zones. EC can be measured using two different sensors – a contact sensor or a non-contact sensor. Contact sensors, such as a Veris machine, have to make soil contact to measure electrical conductivity. Usually, two to three pairs of coulters are used. One pair provides electrical current to the soil while the others measure the voltage drop between them and use that drop to calculate electrical conductivity. Contact sensors usually measure soil electrical conductivity in two different depths, shallow (1 foot) and deep (3 feet).



Veris Machine for measuring EC

There also are noncontact electrical conductivity sensors that work on the principle of electromagnetic induction (EM). An EM sensor does not have to contact the soil directly. The EM method is based on the measurement of the change in mutual impedence between a pair of coils on or above the soil's surface. Most EM instruments are comprised of two or more sets of coils. These coils are electrically connected and are separated by a fixed distance. The transmitter coil (primary field) is used to generate an electromagnetic field at a specific frequency. This causes electrical currents to flow in conductive materials in the subsurface. The flow of currents in the subsurface, called eddy currents, generate a secondary magnetic field, which is sensed by the receiver coil. The magnitude of the secondary field sensed by the receiver depends upon the type and distribution of conductive material in the subsurface. Both the induced secondary field and the primary field are detected at the receiver coil. Non-contact electrical conductivity sensors typically have greater measurement depth than contact sensors.

6.4 - Aerial Images

Aerial images can be collected using satellites, planes or UAVs (unmanned aerial vehicles), and they all have the ability to collect large amounts of data in a short time and are non-invasive. A multitude of data layers can be collected depending on the sensor used: from digital high resolution and multispectral cameras, to soil brightness scanning and thermal imagery.

6.5 - Machine mounted remote sensors

Optical sensors can be mounted on machines to measure crop variation and adjust inputs real time. The Yara N Sensor measures the light reflected off the crop canopy to assess the amount of chlorophyll in the plant and then adjusts the amount of nitrogen applied to the crop. Optical sensors are also used for the site specific treatment of weeds with a weedseeker, where only the weeds get sprayed and not all the field.

Our own tractor and sprayer working in a field of wheat, using auto steer, sectional control, auto boom height control and recording a biomass scan using a Yara N sensor for future reference

7 - Variable rate irrigation

Variable rate irrigation (VRI) is the site specific application of water according to a prescription plan. VRI has the potential to adjust water application rates across different crops, soil types, slopes and low lying areas, as well as avoiding obstacles and no-water areas. During my travels I witnessed some excellent examples of how VRI is having a very positive effect on crop management and water use efficiency.

7.1 - New Zealand

Having last visited New Zealand's Canterbury plain in 1997 the transformation to 2014 was amazing. The rise of the dairy industry and with it irrigation was phenomenal. Whilst visiting Craige Mackenzie in Methven, I got my first real insight into the potential of VRI. Craige, who is an early adopter of PA, which is in its infancy in NZ, has seen up to 30% water savings by using VRI compared to a uniform application. The starting point for VRI is to establish soil type zones using EM scans; once these zones are defined a moisture probe is installed in each different zone to record the actual available water. The moisture probe readings are monitored manually once a week to determine if any extra water needs to be applied through the irrigator. The decision to irrigate is based on three soil moisture values:

-**Field capacity (FC)/ (Full Point)** is the amount of soil moisture or water content held in soil after excess water has drained away.

-Permanent wilting point (PWP) - When the soil moisture falls to this level, plants have wilted and will cease to grow.

-Stress point (SP)/ (Refill Point) - The point where the roots cannot extract water at the rate required, so the plant will be under 'stress'. Stress point is also known as the refill point, and is approximately half way between Field Capacity and Permanent Wilting Point.

The objective is to keep the soil moisture between the refill point and the full point. By using VRI it is possible to only irrigate the zones where it is necessary and apply the correct amount of water to

Centre pivot irrigation using VRI

each zone. This minimises over application which results in soil erosion and nutrient leaching, at the same time as avoiding under application which results in yield loss and plant stress.

Once the decision to irrigate is made, a prescription plan is created on the office pc which is sent to the VRI controller on the irrigator via the internet. The VRI controller reads the plan and sends a message to wireless nodes along the length of the pivot. The nodes control each individual sprinkler to turn on or off, or pulsate according to field position and desired application rate. Craige can monitor the application from his office or phone, and make adjustments if necessary. Whilst I was visiting, the end gun on the centre pivot irrigator was watering part of the road, so Craige, on the office computer, increased the area not to be irrigated and sent the new boundary to the VRI controller, which stopped watering the road.

Adopting VRI has seen water savings of 20% and has removed 8ha overlap between different irrigators

Another Canterbury farmer using VRI technology whom I visited was Eric Watson, who farms 490 ha near Ashburton, of which 96% are irrigated. Since adopting VRI Eric has seen water savings of 20% and has removed 8ha of overlap between different irrigators. Eric showed me a fantastic example of using precision farming to manage soil variability in a field which straddled the old river terrace that has now been levelled off, but is still treated as two fields but with no physical boundary. The top of the old terrace was a heavier soil type and had a crop of peas, which were nearly ready to harvest, whereas the lighter soil below the old terrace was growing forage maize. By using VRI, not only is it possible to change irrigation rates as soil types change, it was also possible to keep watering the forage maize without watering the peas which would be harvested as soon as the irrigator got to the end of the field in about two days. Eric would then have a small window to harvest the peas before the maize needed irrigating again.

Maize and peas planted to match soil type

Irrigator using VRI to only water maize crop in background and not peas in foreground

Each of the above examples relies on moisture sensors and rainfall manually checked weekly to determine the need for irrigation.

I visited Peter Mitchell a farmer from near Oamaru, Otago; the rolling topography of northern Otago raised some more challenges to the efficient use of water. Peter was working with Landcare Research on a project to monitor moisture sensors remotely using telemetry. VRI was being used to match application rates to not only soil type, but also slope and aspect. Early in the season 15mm of irrigation was applied to all areas, once a week. Later this was reduced to 10 mm on slopes and valley floors and 5 mm on hill tops. Less water was applied to hill tops than the slopes and valley floors, due to the natural water movement downhill and the hill tops' lower yield potential. Irrigation was also reduced to south facing slopes (would apply to north facing slopes in the northern hemisphere) where evapotranspiration is lower, and this provided better soil condition, in an area that would normally cause problems with the irrigator getting stuck.

The wireless soil moisture sensors were taking readings every 15 minutes and transmitting the data to a base station at the centre pivot, where rainfall is also measured. A standard web browser is used to access the soil moisture and rainfall data which is subsequently available to the farmer in real time on the internet. At the moment the sensors don't control the irrigator, but are a means to collect more timely data.

7.2 - Australia

In Narrabri, New South Wales, Australia, I had a meeting with Andrew Smart from Precision Cropping Technologies (PCT), a company set up by Andrew specialising in Precision Agriculture data management. PCT worked with John Deere to develop i-grade, John Deere's land levelling system which is used for land forming land to be ready for flood irrigation. The standard approach to levelling a field before flood irrigation is to achieve a constant fall between the entry ditch (where the water comes from) and the tail drain (where the water goes to), by using a laser level. By using RTK elevation data PCT have produced software to design a grading map that follows more closely the contours of the ground and minimises soil movement. The field slopes towards the tail drain with an inconsistent fall, but is always steep enough to maintain water flow and drainage.

Land forming bucket using GPS levelling

Flood irrigation control

8 - Site specific weed management

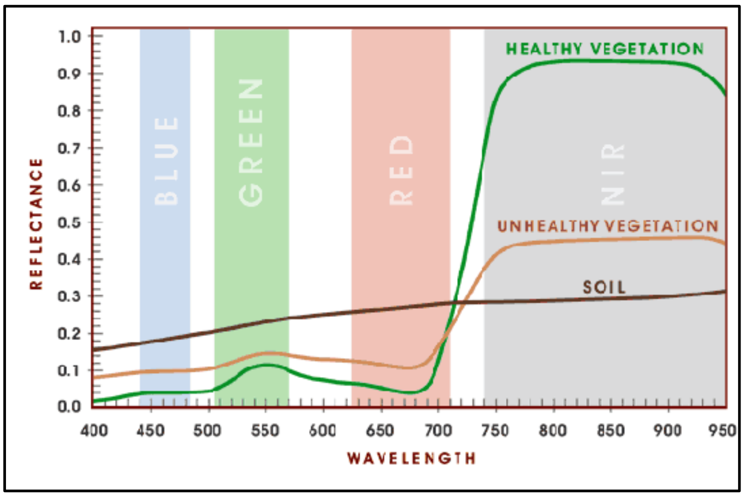
Site specific weed management (SSWM) is the targeting of weeds or weed patches within a field situation without treating the whole field. SSWM can be split into two approaches:

- **Passive**, where the weeds/weed patches are recorded for future management, or

- **Active**, where the weeds are identified and treated in real time.

8.1 - Optical sensors

The fundamental of SSWM is the ability to identify weeds and differentiate them from the crop. Optical sensors are used to measure the reflectance across a range of light wavelengths. Due to the difference in colour between the weeds and the crop, different wavelengths will be absorbed and reflected. Resulting in a unique reflectance curve, the steep part of the reflectance curve is known as the "Red Edge", and is individual to a plant and its position acts as an identification marker. Once this information is linked to a GPS system, the weed patches can be identified and spatially located. The data collected will be analysed by a step-by-step mathematical procedure called an algorithm, to produce a weed map.



Source: extension.USA.edu

8.2 - Mapping blackgrass

Ursula Agriculture, whom I visited in Aberystwyth, are using multispectral optical sensors fitted to fixed wing UAVs to map blackgrass in cereal crops. The fields are assessed in the late spring and early summer before the crop is harvested, when the blackgrass is above the crop canopy. The UAV can map 150ha during its 40 minute flight and has an on-ground resolution of 15cm. The purpose of mapping the blackgrass areas is to aid weed management in the following crop, which could be higher rates of herbicides applied to the weed areas, or higher seed rates to increase competition through the use of a VRA prescription. Ursula are looking to develop this technique to include a wider selection of weed species, including weed beet in sugar beet crops, and brome grasses.

I also visited Reading University, where Dr. Alistair Murdoch is working on a project using digital cameras mounted on a sprayer to map blackgrass. The system involves mounting 4 cameras on a 24 metre wide sprayer, at 1 m above the crop, and can capture an image every metre if the sprayer is travelling forward at 14 kph. This effectively captures 1/6th of the field, but it is at a very high resolution of between 0.5 mm and 1 mm and can identify individual blackgrass heads which are 3-6 mm across. *"We are creating a probability map, not a blackgrass map*" says Dr. Murdoch, because not all the field is covered and there will be weeds that are not detected. The data is stored on the machine and processed on the machine before being sent to a third party to create an application map. As the system is passive the image analysis does not need to be done quickly, hence can be done on the machine, and as it is processed on the machine the amount of data that needs to be transmitted is greatly reduced.

8.3 - Active systems - the next step

The ultimate goal of SSWM is to be able to identify a weed and target it in real time. During my visit to Agritechnica, in Germany, I saw the H Sensor, on the Agricon stand. The 'H' stands for herbicide and the sensor aims to target and reduce herbicide inputs. The sensor is able to distinguish between crops, grass and broadleaf weeds. In cereals the sensor accurately identified blackgrass between 80 and 90% of the time. Another trial showed a herbicide use reduction of 35% as broadleaf weeds were not present in 28% of the field. The sensor is mounted 75 cm in front of the nozzles on each section of the sprayer boom, in this case there were four, and switches the boom on or off depending on the detection of weeds. The camera gathers 10 images per second and has an on ground resolution of 0.5 by 0.5 mm, over a 0.5 m width. Weeds have been successfully sensed in a range of crops until canopy closure, and as it is an active sensor with its own light source it is independent of daylight and not influenced by stubble or stone. The system could be adapted to identify new weeds. Images of the weed at various growth stages would have to be captured, and algorithms developed for that specific weed.

H sensor used for Site specific Weed management

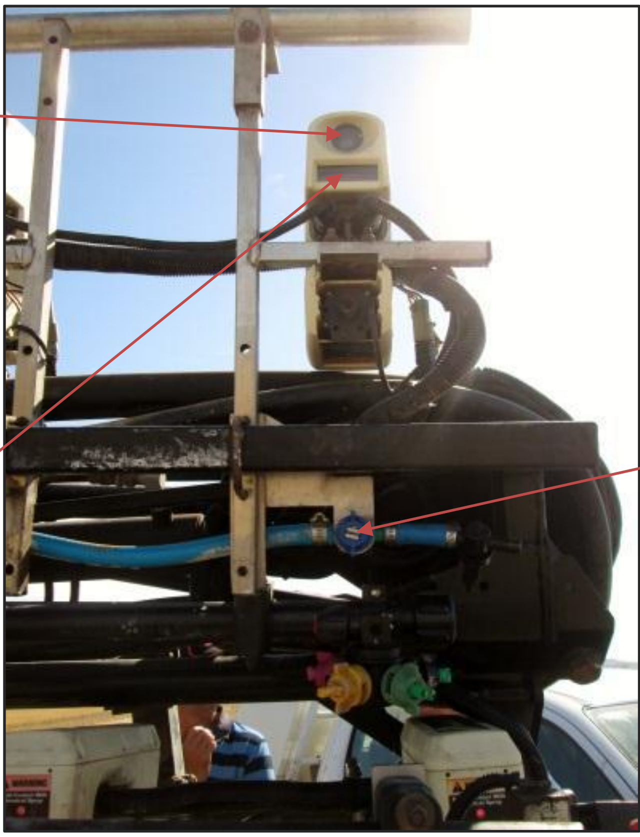
8.4 - Trimble® WeedSeeker®

The Trimble® WeedSeeker® spot spray system is an effective solution to efficiently control weeds. The WeedSeeker® system uses an optical sensor to sense if a weed is present and signals a spray nozzle to deliver a precise amount of chemical - spraying only the weed and not the bare ground. It is most effective in areas where weeds occur intermittently. When a weed enters the sensor's field of view it signals a spray nozzle to deliver a precise amount of herbicide to that weed only. WeedSeeker® technology uses sensors and nozzles spaced at either 300 mm or 380 mm apart. This is due to the narrower field of view associated with the WeedSeeker® sensors compared to a 500 mm spacing on a standard boom, allowing you to maximise potential chemical savings. Herbicide is reduced by between 60-90% on most spray applications.

I visited Dave Brownhill who farms on the Liverpool Plains, NSW, Australia. Dave was using a weedseeker to spray his summer fallow to clean up the difficult weeds. Due to the climate there is often a long summer fallow period when a crop is not established, but the summer rains are filling the soil water profile ready for the next crop. During the summer fallow period there is an opportunity to spot-spray the weeds that germinate after a rain, several times. As only a small percentage of the field is sprayed - typically 15%, but can be as low as 4% - the application rate is increased (20-30%) on the areas that are sprayed to ensure a good knockdown of weeds. The machine paid for itself within a year in terms of reduced pesticide applications.

LEDs produce a combination of infra-red and visible red light which is project-ted onto the target approximately 600 mm below the sensor

The light reflected from the target is detected by the sensor



The reflected light detected is analysed and if it matches the light reflected from a green plant the fast fire solenoid is activa-ted to only spray the plant. The sensor has the capability to detect plants from approximately 7cm upwards in diameter

Underside view of Trimble Weedseeker showing the different parts

9 - Nitrogen

As nitrogen is the most important nutrient applied to most crops and has the greatest impact on yield it is paramount it is applied as effectively as possible. In 2008 following a huge price increase in ammonium nitrate, the main nitrogen based fertiliser we use, we started to use a Yara N-sensor to variably apply nitrogen to make the most of the nitrogen applied. I am convinced of the merits both economically and environmentally, of only applying the right amount of nitrogen in the right place. I wanted to find out if what we do is the best option or could we improve?

9.1 - Germany, UK and Canada

I visited the Yara research station in Hanninghof, Germany, to find out more about the research behind the N-sensor and see if it could be used for other applications in the future. The background research is very detailed, from pot trials in the greenhouse to field scale trials on different soil types and different climates to match the country where the sensor will be used, which gives me confidence in the accuracy of the sensor.

Yara N-sensor team

I was hoping they would tell me that they had written an algorithm for an absolute nitrogen application on wheat, where the sensor would measure how much nitrogen is required by the plant, in the same way that the absolute N program we use effectively on OSR: as opposed to making a management decision on how much Nitrogen to apply at a particular growth stage, and altering the rate around that amount depending on the relative crop condition to the average measured by the sensor. Unfortunately due to the physiology of wheat the rate of N mineralisation is slow. Nitrogen mineralisation is the process by which organic N is converted to plant-available inorganic forms. Timing between split nitrogen applications and plant growth stage is critical, and these factors make an absolute N program for wheat too unreliable. This concurred with the research done by Dr. Daniel Kindred, ADAS in the UK, looking at Nitrogen use efficiency and the ability to predict Nitrogen requirement using a remote sensor.

NDVI is a statistical analysis of the different reflectance measured in the visible (red) spectrum and the near infra-red (NIR) spectrum. NDVI has a range of -1 to 1

The alternative to using an optical sensor, such as an N-sensor, for VRA of nitrogen, is to use a previously captured image by a plane or satellite. The most common method is to use a NDVI (normalised difference vegetative index) image and convert it into an application map that can be exported to the controller on the fertiliser applicator. I visited SOYL, the largest provider of this service in the UK. SOYL offer a service called SoylSense, which now captures 12–14 satellite images during the main growing season, which is a big improvement compared to 3-4 images when the service was first launched. The more images captured increases the probability of getting reliable data and avoiding cloud cover which was an issue in the past. The satellite images are calibrated using a ground-based sensor, to ensure correct recommendations.

In Canada companies such as Agri-trend and Farmers Edge are actively promoting the use of remote imagery to create nitrogen application maps. They use either satellites or planes to gather the data, as it is possible to gather large amounts of data quickly. The crop grows very quickly so the window of opportunity to apply the nitrogen in crop at the correct growth stage is very tight compared to the UK. Therefore the majority of the crop's nutrition is applied at the same time as planting, using historic yield data and satellite imagery to create yield potential zones.

9.2 - Mexico

In Mexico farmers apply 75% of their nitrogen before planting wheat, then irrigate the wheat 20 days after planting and can lose up to 20% of the Nitrogen. The remaining Nitrogen balance is bubbled into the second irrigation of 80-100 mm of water, as anhydrous ammonia with enormous losses of up to 75%. Scientists at CIMMYT, are conducting Nitrogen trials using N-rich strips and a handheld greenseeker, an optical Nitrogen sensor sold by Trimble, to evaluate if crops are Nitrogen deficient and how much Nitrogen needs to be applied. Often farm practice results in excessive and inefficient application, whereas the use of a Nitrogen sensor has seen Nitrogen applications reduced by 25%. Ivan Ortiz Monasterio, the scientist leading the research, has also been studying remote monitoring of phosphate deficiency. Dr Monasterio thought that any meaningful results from this research were two years away at the time of my visit. Phosphate deficient plants were seen to be small and green, whereas nitrogen deficient plants were seen to be small and yellow. Therefore an algorithm which could differentiate between colour and biomass would be required.

Scientists from CIMMYT

9.3 – Brazil

The final visit of my overseas travel was with Professor Jose Molin, at the University of Sao Paulo in Piricicaba. I had spent ten days in Brazil and seen very little evidence of the use of PA, mainly due to the abundance of cheap labour and land. Professor Molin and his team were studying how remote nitrogen sensors, like the N sensor, could be not only used for wheat but also other crops like sugar cane.

9.4 - New Zealand

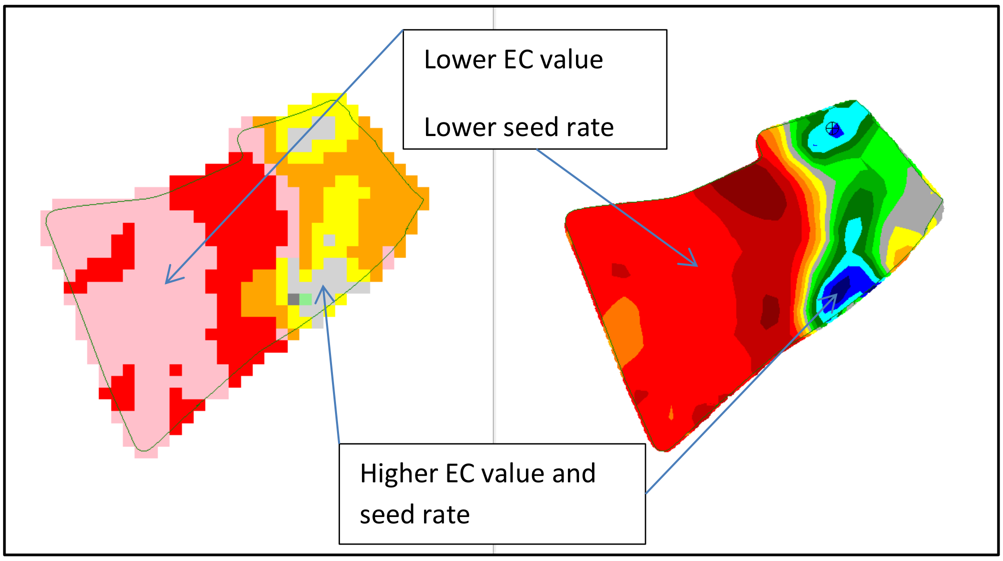
New Zealand dairy farmers are using optical sensors to help them avoid applying nitrogen to the very highly nitrogen-rich urine patches in grazed pastures, that would lead to nitrate leaching because of over fertilisation. Agri Optics, a company started by Craige Mackenzie after completing his Nuffield Farming Scholarship, has developed a product Smart-N. Smart N uses visible and NIR sensors to identify the nitrogen-rich urine patches of the grazed pasture, which are not treated by using liquid nitrogen application techniques. The smart-N sensor works in the opposite way to a weedseeker sensor, and the sensors can be further apart, at 50 cm. The system is also capable of delivering a nitrification inhibitor, which slows down or "inhibits" the conversion process of nitrogen from the relatively immobile ammonium (NH4) form to the mobile nitrate (NO3) form, to those identified patches to further reduce the chance of nitrate leaching. Not only is there an environmental gain from this technology, but trials have shown a 30% reduction in fertiliser usage.

Enjoying the Brazilian sunshine with my friends and travelling companions:
Niall Armstrong, Tom Sewell, Charlie Russell and Bec Hill

10 - Variable rate seed

It is often considered that the most important day in a crop's life is the day it is put in the ground. The genetic potential is set at that point and subsequent events and actions will determine the final yield. Variable rate seed gives farmers the opportunity to plant the correct seed density across the whole field irrespective of soil type, stone content, water holding capacity, aspect and topography, to ensure a healthy and profitable crop is achieved. Establishing a plant population that is too high can lead to overly thick canopies, increased lodging, higher disease pressure and unnecessary expenditure on seed. Plant populations that are too low will result in lower yields and higher weed pressure.

As discussed earlier in chapter 6.3, the best way to measure changes in the soil's physical properties is electrical conductivity. Areas of similar conductivity values are zoned, and each zone is assessed for texture, slope, stone content, soil depth to subsoil, and compaction. This allows the creation of potential seed rate zones. The seed rate is adjusted in each zone to establish the optimum plant population, taking into account the inherent soil variability. For example, an area of high clay content or high stone content may have high plant losses and therefore a higher seed rate is required to compensate for this. The zones should be designed relative to each other, and the final seed rate decided on the day of establishment, taking into account local variables such as date and seed thousand-grain weight.



Comparison of Seed rate (L) and EC (R) maps

EC (electrical conductivity) maps form the basis of variable rate seed maps, but other layers can be added such as weed maps, yield potential and pest maps.

The resolution of the seed rate map is restricted by the controllability of the machine planting the seed, therefore if sectional control is used the effects can be enhanced. During my visit with Mark Waibel, see chapter 5.4, we discussed Precision Planting's vDrive technology. vDrive controls the individual metering units on row crop planters with an electric motor, allowing the rate to vary from row to row and along the row to match a variable rate prescription plan. Another advantage of the vDrive system is the capability to maintain the desired plant density across the width of the planter as it turns around a corner, where the metering units on the outside of the arc will be travelling faster than the one on the inside.

Comparison of vDrive to conventional planter

The above tablet screen shot shows using Precision Planting's fieldview[R] software; the uniform (all orange) plant population achieved using vDrive around a corner compared to the other pass (multi-coloured) using a conventional row planter. This avoids sub-optimal and excessive plant populations which would result in potential yield penalties.

11 - Base fertiliser: lime and gypsum

Many farmers' first step into PA is the variable rate application of base fertilisers such as phosphate (P) and potash (K). It is relatively easy to demonstrate cost savings when applying base fertilisers according to the requirement of each part of a field as opposed to a flat rate. To enable VRA of base fertiliser the soil has to be sampled, normally using a grid method involving taking multiple soil samples around a geo-referenced point in the centre of each square in the grid to form a composite sample for that square. A standard soil sample analysis will measure P, K, Mg and pH, both as an absolute value and an Index. It has been extensively shown that applying nutrients to soils where they are already present at certain levels, shows no yield improvement. Therefore by sub dividing the field into small grids, typically 1 ha, those parts of the field will be identified and not require any extra base fertiliser to be applied. This reduces the quantity of fertiliser used and applies the fertiliser more intelligently.

After seeing the benefits of VRA of P and K, farmers are also using the same grid samples to VRA lime, to address soil pH levels. PH is often overlooked but affects the availability of many other nutrients in the soil profile and how they react with each other. Lime can be used to maintain soil near a neutral state with a pH index of 7. Tony Ludeman, who farms near Shepparton, NSW, Australia, was using VRA lime across 5000 acres of wheat and canola (oilseed rape). His annual budget for lime was half what it was before using VRA and the savings in lime were three times the cost of the sampling. The VRA was based on EM data at 35 cm soil depth. The same data is also used to apply gypsum (calcium sulphate dihydrate, $CUSO_4$ $2H_2O$). Gypsum is used to ameliorate sodic (High Sodium content) soils, which are common in warm arid climates. Sodicity is known to restrict plant growth. Zones that are identified using the EM data can be tested for levels of sodicity, and then treated with gypsum accordingly.

11.1 – On-the-go pH testing

Veris technologies have developed the pH manager, an on-the-go pH tester that is incorporated into the Veris EC toolbar. With typical grid sampling, soil samples are taken every 330' (100m). Computer software fills in the gaps to make a nice-looking lime spread map. But there's a serious problem on most fields: pH varies more than grid sampling can handle. When 2.5 acre (1ha) grid lines are overlaid on pH maps from the Veris pH manager, the pH variability within each grid is fully exposed - and the pH within each grid can vary as much as it does in the entire field! The pH manager uses a shoe that is lowered into the ground and collects a soil sample which is then raised up against a pair of pH electrodes to test the pH, before being lower back into the ground to collect the next sample which ejects the previous sample. Two electrodes are used to give better accuracy. If the two electrode measurements differ by more than 0.5 of a pH unit the reading is discarded. Discrepancies between the electrodes can be caused by clay sticking to the electrode, stones, stubble and incomplete soil cores. The electrodes measure pH in millivolts which is converted into a pH value by the on-board computer, geo-referenced and stored. Up to 25 samples can be collected every hectare, depending on forward speed and distance between sample tracks, compared to 1 with grid sampling. The pH electrode is washed using a spray nozzle between each sample.

See photo on next page.

Soil sampling shoe with pH electrodes above

I visited Kym I'Anson from Marrabel, SA. who is working with Dr. Brett Whelan, University of Sydney, to assess a Veris machine set up to measure EC and pH on-the-go. Kym operates a 36m CTF system and samples between each wheel track, with a forward speed of 10km/h resulting in 12-15 samples per hectare. Due to the accuracy of the wheel tracks the sampling shoe is mounted to run between the rows of stubble or crop, to avoid blockages and residue. The hydraulic pressure on the sampling shoe is critical to getting consistent soil cores. It has to be high enough to penetrate the ground but not too high that it causes the machine to bounce. Soil consistency is important for soil core quality; it has to be moist enough without being too wet. Kym's land can be divided into three soil types, which have been previously soil-sampled on a grid system. 70% is red brown clay loam, which is acidic (pH 4.4-5.5), sodic and prone to water logging, very hard to imagine at the time of my visit! 20% is acid grey shale located on the ridge tops and the last 10% is neutral free-draining cracking black soil. Over the past 10 years the red-brown clay loam has had three applications of both lime and gypsum. The grey shale has only had one or two applications of lime and no gypsum, while the black soils have had nothing. By increasing the sample frequency using the automated testing, Kym's' confidence in the soil type boundaries has increased and he has reduced the areas that require high rates of lime by 25%, further reducing the lime requirement.

> *"Using VRA as opposed to a blanket rate, has saved over 1000 tonnes of lime and gypsum"*
>
> *Kym I'Anson, SA*

12 - Data – the glue that holds PA together

Data is the fundamental building block of PA, whether it is a satellite correction signal for GNSS or a soil sample used to create a VRA prescription plan. Collecting the data is the easy part; interpolation of the data is more complex, particularly with prescription maps. Data points collected can highlight both spatial and temporal variability within a field. **Spatial variability** is the variation found in soil, terrain and crop properties across an area at a given time: for example soil pH or crop yield. **Temporal variability** is the variation found in soil and crop properties within a given area at different measurements in time. For example the difference in yield maps from one year to another. Many factors can contribute to the spatial and temporal variability. Understanding the effect each factor has can only be measured and managed using PA and statistical analysis of the data.

I visited Agri-Trend, a company set up by Rob Saik in 1997 to give Canadian farmers an alternative source of advice from input suppliers. Agri-Trend's mission is *"to help farmers allocate scarce resources to produce a safe, reliable and profitable food supply in an environmentally sustainable manner"*. Agri-Trend use PA extensively to target inputs more accurately, through the use of management zones. Along with Rob, CEO, I also met Warren Bills, President of Agri-Trend Geo solutions and Matt Gosling, an agri coach (agronomist). Agri-Trend geo solutions is the PA part of Agri-Trend. Matt works as an independent agronomist, but has the support of the wider Agri-Trend network of over 170 people. Agri-Trend demonstrated a strong link between agronomy and PA, with agronomists like Matt working closely with GIS (geographic information system) specialists in Warren's team. We visited farms that were using VRA of fungicides to control sclerotinia in canola (oilseed rape). Canola is an important crop in Canada and one of its biggest threats is the disease sclerotinia, which is controlled with fungicides applied during flowering, but does the whole field need to be treated and at what rate? An aerial image of the crop is captured and divided into management zones, the management zones are ground-truthed by an agronomist, who then decides how each zone will be treated and an application plan is created. Where you have a dense crop stand and canopy there is a significantly higher risk of sclerotinia than in those areas where the crop is less dense and has lower yield potential, therefore it is logical to target a higher rate of fungicide on the areas at greatest risk.

Myself with Warren, Matt and fellow NSch Jake Freestone

Warren described how the agronomists use the "20:20" rule: if the chemical cost is over $20/ac and more than 20% of the field is not going to be treated with a reduced rate a variable rate application will be used instead of a flat rate.

Another farmer I met in Canada was Terry Aberhart, who farms in Saskatchewan and runs a consultancy business as part of the Agri-Trend network. Terry is a committed adopter of PA and had done extensive on-farm trials of variable rate fungicides in canola. Through his trial work he had seen no yield advantage in applying a sclerotinia fungicide on crops with a yield potential below 0.7

T/ac, but a yield increase of 0.15 T/ac on crops with a yield potential over 0.9 T/ac. Terry uses Agri-trend's Agri-data software for crop recording and variable rate application maps. As it is cloud-based he is able to see his data on his smart phone or tablet. This is very convenient and useful to be able to monitor how crops are responding to treatments during the growing season, without physical markers in the field.

12.1 - Optimizer

Daryl Starr

Whilst in Indiana I spent a day with Daryl Starr the founder of Advanced Ag Solutions, (AAS). Daryl started his company in 2006 after leaving the family farm. AAS offers services including soil sampling, crop scouting (crop walking) and has also developed some yield prediction software known as Optimizer, which at the time of my visit (July 2013) was being used on 350,000 acres and across 27 US States. I was keen to find out how Optimizer was being used to help farmers make better informed decisions.

Optimizer is currently specific to corn (maize) as it is the main crop in that part of USA, with many farms growing only corn. It can be used as a planning tool or an in-crop decision-making tool. It combines the variability of the major inputs of a corn crop, soil, seed, fertiliser and weather. Some of this data is known, such as soil type, seed characteristics, and up-to-date weather data, and some such as future weather is predicted. Optimizer amalgamates all the data across the different field zones and produces a yield prediction and also shows the potentially yield limiting factor. As optimizer is web based it allows farmers, agronomists and anyone else the farmer wishes to see their data to quickly compare how different management options impact yield. It also allows farmers to change management decisions for each zone from year to year, as even though soil zones are constant the best year on year management can be variable.

12.2 - Precision Ag *not* Picture Ag

In Narrabri, NSW, Australia I met with Andrew Smart of Precision Cropping Technologies (PCT). Andrew founded PCT in 2001 with three cotton growers in the Narrabri region and now has thousands of clients across Australia, New Zealand and the USA.

> *"We are in the business of Precision Ag not Picture Ag"* Andrew Smart, PCT

Andrew was adamant that he and the rest of the PCT team are not in the *picture* Ag business but in the *precision* Ag business! This statement refers to the fact that an awful amount of precision Ag data is only ever used to create some pretty coloured contour maps which are glanced at once, then confined to a folder. PCT have written a very powerful software package called Gateway to interpret PA data. Raw data such as yield and soil EC maps, or RTK elevation is processed by PCT and the cleaned data is stored on the PCT server for future use. The data is easily accessible and can be cross referenced with other data layers in the program to understand what is causing any variation. The software looks at trends in data sets to identify, for example, what is having the greatest effect on yield. By carrying out detailed statistical analysis on the data the degree of variability can be quantified, and the potential gain of a subsequent VRA can calculated. A large part of PCT business is based around variable rate irrigation (VRI), including land levelling as described earlier in chapter 7. Another benefit of Gateway is modelling the effects of different pivot irrigator VRI prescriptions on output and return on investment to install VRI.

13 - Discussion

During my Nuffield experience and travels I met some amazing and inspiring farmers, as well as seeing some remarkable farming practices. I strongly believe that farmers in the UK who are already involved with PA are some of the most advanced adopters in the world, because of the intensity of the cropping and also due to the relative slow growth and long growing season. The difficulty I often found was how to transfer this knowledge to improve how I farm in the UK.

13.1 - Machine control advantages from Precision Agriculture

A good example of this is CTF. I can completely understand why the Australian farmers I visited are seeing huge benefits from using CTF. It absolutely makes logical sense to limit the percentage of a field that gets driven on by the very large heavy tractors and implements they have to use due to the scale and time frame in which they operate. In the countries and farming systems that CTF works it will have a dramatic positive effect on production, resource utilisation and soil health.

There are two major obstacles in the UK to the widespread adoption of CTF: field size and accessibility. Field size or, more importantly, the proportion of a field which is headland, as CTF is not possible on headlands that are turned upon, is far greater the smaller the field. **See Appendix 2.** Our average field size is 12ha which, if the fields were square - which they aren't - would result in a headland percentage of 27.71%, whereas with an average field size of 100 ha, which is very plausible in Australia, the headland percentage is only 14.8%.

The second point is that of accessibility, because the most efficient machine setup is to have all machines using the same wheelings involving 3m centre track widths. This would have implications for moving tractors and machines along UK roads which are considerably more congested and narrower than in rural Australia. Both these issues can be addressed and some farmers in the UK are moving towards CTF with success, but the areas where it can work are limited. On our own land the advantages of changing to a strict CTF programme would not outweigh the disadvantages, but we can make changes to limit how much of our soil is driven over. We may need to change our current policy of selling straw to neighbouring livestock farmers, which can result in soil damage from trailers as the concept of controlled traffic to them means getting out of the field without hitting the gate posts!

13.1.1 - Inter-row seeding & Implement steer

Inter-row seeding is also very relevant in the countries where row crops, such as maize or soya are grown, or broad acre crops like wheat on wider row widths. The placement of the seed is changing as the technique is better understood and the accuracy is improving. Instead of planting the next crop equidistant between the previous crop rows, it is being planted alongside the old stubble row. Far enough away so the stubble doesn't get disturbed and cause any blockage problems, but close enough to benefit from the increased water availability and better soil structure created by the previous crop's root system. Inter-row seeding works very well in direct drilled crops with full stubble retention, in hot and dry climates. The stubble acts as an insulator to the soil to reduce the soil temperature and retain valuable soil moisture in the upper soil layer, and prevents soil erosion from wind and rain. In the UK closer row spacing is used normally following some form of cultivation, so the opportunity to inter-row seed is not as obvious. Although by using RTK guidance the seed can be accurately placed to either bisect the previous crop rows or align with them and, even though the stubble will not be retained, the residual benefit of the previous crop's root system on the soil structure will be harnessed. For example, if wheat was planted after a nitrogen fixing crop such as beans it would be most advantageous to plant it in the same rows to maximise the residual nitrogen fixed by the bean, which will move down through the soil profile and not laterally across it.

Implement steer has the effect of magnifying the gains from inter-row seeding purely by improving the consistency of seed placement accuracy, thus increasing the proportion of seeds placed in the optimum environment for greatest yield potential.

13.1.2 - Down force control

Another aspect of seed placement control which would be beneficial to UK agriculture is hydraulic coulter down force control. As soil varies across fields so does seed placement. In heavier soils it could be too shallow or even on the surface, whereas in lighter soils it may be too deep, resulting in an unevenly established crop. The down force control seen in the USA could be used on precision planters in the UK for row crops like sugar beet or maize, on an individual row basis. On standard drills, to vary the down force across the entire coulter bar would be sufficiently adequate. As the standard drills in the UK typically range from 3m to 8m, there would not be a huge variation in soil type across the width of the drill compared to the variation along the length of a run. If the drill is divided into sections and controlled independently this would obviously be advantageous, but not a necessity, and as is always the case the extra cost would need to be returned by an increase in yield.

13.1.3 - Sprayer control

Compared to some of the other countries I visited, farming in the UK is very much more on display to the general public and their perception of farming is important. The UK countryside is very open and accessible, therefore it is important that the agricultural practices the public sees are perceived to be good. One of the most contentious topics is spraying. The accuracy and efficiency with which pesticides are applied can be greatly improved with auto section control of smaller sections or even individual nozzle control, coupled with other technologies like PWM (pulse width modulation) to minimise spray drift and turn compensation to increase efficacy as the boom tips travel at different speeds. This has a twofold benefit: it is good for the crop due to improved accuracy and the image the general public sees is of an efficient technologically advanced machine carrying out a job which they perceive to be best practice.

13.1.4 – Autonomous grain cart

The autonomous grain cart Kinze are developing amazed me and was the first autonomous tractor concept that really made sense to me. Other concepts of lots of little machines working in harmony with each other with only limited input from a human operator still seems a long way off in my opinion. For a much more in-depth look at autonomy in agriculture see the 2012 UK Nuffield Farming Scholar report by James Szabo, as opposed to my giant sweeping statement. The thing that impressed me about the Kinze grain cart was that it was simple, adaptable and user friendly. If the tractor was not being used to pull the grain cart it could be used for other tasks. I see no reason why this technology could not be used on large farms in the UK that are already using a grain cart. The fact that the tractor which is operated autonomously in the field is a standard tractor, albeit heavily modified, means that when it comes to moving between fields or farms on public roads it would be no different to any other tractor. Other autonomous tractor concepts may not be road-legal or require specialist transportation.

The capability for one operator to control multiple machines via a remote terminal could be employed in the potato planting process where often several machines perform the same task within close proximity. This reduces the overall labour requirement, although requiring the operator to have different skills but at the same time efficiency is improved.

13.2 - Variable rate applications

Farmers are renowned for complaining about the weather, but in fact the UK climate is the jewel in the crown. It is variable and inconsistent, but at the same time is reliable. UK agriculture does not suffer from a boom and bust cycle seen in other countries with extreme heat and drought; the average yields will be very similar from year to year. The main reason for this is the length of the growing season, for if the crop experiences a very dry or wet period in its growth, there is usually time for the crop to recover to a degree and not be totally lost.

The length of the growing season and the slow development of crops make the UK perfectly suited to benefit from Variable Rate Applications (VRA), due to the opportunity to measure variation and act accordingly. This was brought home to me during my time in Canada. Canadian farmers and advisors know that if they applied more nitrogen to wheat during the growing season instead of at planting, they would see increased yields, but due to the rapid growth rate the window of opportunity to apply the nitrogen is too small, and hence too risky. It also coincides with spraying the crop with herbicides and fungicides, which cannot be applied at planting, and therefore are the priority. This clearly demonstrates the advantage of a long slow development where two, three or even four applications of nitrogen can be made in the UK, without compromising the timing of other inputs. Each application can also be applied variably to ensure maximum effectiveness and efficiency of the nitrogen. It is important to understand what you are hoping to achieve from a VRA and which variable is being managed. As there is a long time to manage the crop canopy during the growing season with VRA nitrogen. VRA seed maps can be used to create optimal crop establishment, taking into account different soil types, weed burden, pest burden and topography.

> *The length of the growing season and the slow development of crops make the UK perfectly suited to benefit from Variable Rate Applications*

If seed and fertiliser are being successfully applied variably, why are not more pesticides applied variably? The problem with VRA of pesticides in the UK is that they are very rarely used in isolation, but a combination tank mix will be used. There is a very good argument for using VRA PGR (plant growth regulator), where over-application suppresses yield. However a PGR is often mixed with a fungicide or herbicide, which would not necessarily benefit from being applied variably in the same way. It would have to be demonstrated that the gain from applying a PGR variably in isolation outweighed the extra cost of additional spray passes, as well as having the capacity to include another operation.

13.3 - Site specific weed management

Site specific weed management (SSWM) will become more widely adopted as the cost reduces and the options increase. The choice of SSWM technique used, either passive or active, will depend on the year, crop and the problem. The passive systems using an UAV to map the weed infested areas are best suited to treating perennial weeds such as blackgrass, as once the areas are identified they will remain static as the seed is not greatly dispersed. These areas can then be targeted in subsequent years to reduce the weed infestation, leading to increased yields and lower costs of production. As the data does not need to be collected on a regular basis, and the processing of the data is very intensive, I don't see this as something growers would do themselves, but would use a third party.

As often mentioned, the downside of using an UAV to map weeds compared to a sprayer boom-mounted camera is the resolution of the image, typically 15 cm, so potentially some weeds will not be detected. Sprayer boom-mounted cameras have a higher image resolution, typically 0.5 to 1 mm, and are capable of identifying individual weeds, but only look at 1/6th of the crop, and therefore will also fail to detect all the weeds. As both approaches create a probability map of the weed a buffer zone around the areas has to be used to ensure all weeds are targeted. Allied to this the best application resolution achievable is 0.5m if individual nozzle control is used, whereas in reality it is more likely to be between 2 and 6m, depending on section size. Thus the image resolution achieved using a UAV is perfectly acceptable.

Another advantage of using an UAV over a boom-mounted camera is that it is non-invasive to the crop, and far more mobile. I struggle to see how a farmer would justify the capital expense of owning a system of boom mounted cameras, as once the crop has been scanned the system is redundant, and the data - for subsequent use anyway - has to be sent to a third party to be interpolated. It would be better if the cameras were owned by the company analysing the data and hired out to the farmer to collect the data.

Active SSWM has great potential and is a technology that could be invested in on a farm scale. I don't think there is a huge market or need for active sensors like the weedseeker in the UK, as our cropping rotations do not include long fallow periods and the capital cost would be prohibitive relative to the financial gain. On the other hand intelligent in-crop sensors such as Agricon's H-sensor could be fully utilised, and could be used to target a range of different weeds in different crops. It is the potential adaptability that makes the H-sensor attractive as it could be used throughout the growing season year after year.

Active SSWM has great potential and is a technology that could be invested in on a farm scale.

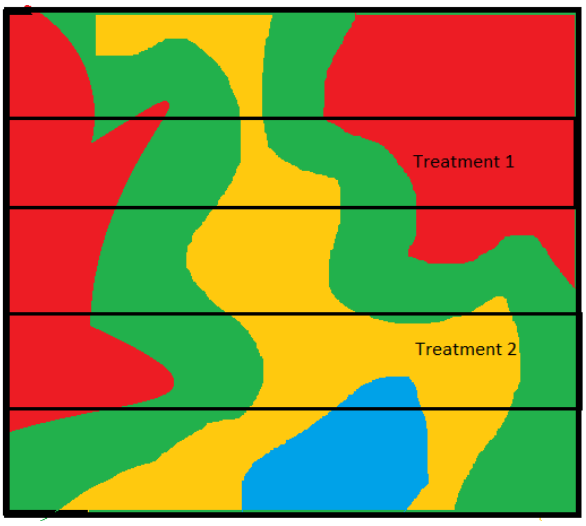
13.4 - Irrigation

Water is a very precious resource and the most important to growing crops, whether it is oversupply or undersupply. In New Zealand and Australia I saw some fantastic examples of how PA is improving the efficiency of the irrigation process. It would be difficult to copy this in the UK, as they were based around centre pivot, lateral or flood irrigation, whereas the vast majority of irrigation in the UK uses rain guns and reels. Field size, shape, location, obstacles and local planning laws, would prevent the mass installation of large centre pivot irrigators. Although there is no reason why existing irrigation equipment could not be converted to VRI (variable rate Irrigation), which would take into account the variability of soil types, water availability, slope, aspect and wind conditions. All of these could be measured and monitored to ensure the optimum amount of water was applied, across the whole field.

13.5 - Data

One of the main aims of my study was to assess how we can use the data collected to quantify the gains from PA. Disappointingly I have not managed to reach this goal. This has turned out to be a very difficult task for many reasons. The biggest problem in assessing the benefit from a particular trial is getting a fair and true comparison, in the real world. If a split field trial looking at comparing VRA nitrogen to a flat rate application is conducted, how can you be sure that it is nitrogen affecting the yield outcome and not some other underlying variability? Much of the difficulty lies in the lack of ability to analyse the data accurately and drill down to see what is the limiting factor, as per Liebig's Law of the minimum "*The availability of the most abundant nutrient in the soil is only as good as the availability of the least abundant nutrient in the soil*." Therefore it necessary to be able to compare many layers of data to each other, all at the same time, to be able to find the limiting factor. By using statistical analysis it is possible to identify trends and measure the degree of variability.

One way of removing much of the inherent spatial variability is to conduct strip trials of different treatments across the different management zones. If the strip trials are set up as a prescription map they can be orientated whichever way is necessary to get the best results, as opposed to traditional strip trials based on tramlines. How the results are analyzed is important for the integrity of the trial. In the trial shown below, the results from each different treatment must be compared across the same zones, therefore results from treatment 1 in the red zone would have to be compared to results for treatment 2 in the red zone.



Strip Trial Treatment comparison

Data has to become more mobile. It is no longer enough for all the data to be stored on the office PC, as more and more farmers and advisors are using smartphones and tablets on a regular basis. Data has to be accessible in the field to allow ground truthing and real comparisons to be monitored, and link PA to the agronomy of the crop. If the full benefit of VRA is to be realised it is imperative that the crop progress can be accurately monitored and recorded. The only way to achieve this it to have the spatial data at hand for whoever is making the assessment, to ensure they are in the correct place and actually assessing what they think they are. This will only become possible as all the different manufacturers of terminals, controllers and data systems become more compatible and open with each other.

I think the use of tablets, apps and bluetooth links will supersede Isobus controllers and will go a long way to solving the compatibility problems farmers encounter.

The Isobus-ISO 1173- machine communication protocol was supposed to improve the data transfer between machines and standardise control terminals, but has had limited success. I think the use of tablets, apps and bluetooth links will supersede Isobus controllers and will go a long way to solving the compatibility problems farmers encounter.

The fundamental requirement of any system is that it must be simple, functional and intuitive to use. The ultimate aim is to be able to share data from any device to another device seamlessly and easily with as minimal interaction from the operator as possible. Eventually this will be done wirelessly and either accessed over the internet or stored on a cloud based system.

There are concerns over wireless data transfer, with regard to who owns the data - is it the farmer or the service provider? I think it should always be the property of the farmer, but will only be of interest to other third parties if it has a value associated to it. The ownership of data could be a complete Nuffield Farming study on its own!

14 - Conclusions

1. UK agriculture is perfectly suited to the widespread adoption of Precision Agriculture due to the intensity of our management systems and the length of the growing season, and will continue to be a world leader in this field.

2. Precision Agriculture will increase production in many ways by targeting inputs more accurately using variable rate application prescriptions that match the input to the area's specific need. Prime examples are variable rate irrigation and site specific weed management.

3. Precision Agriculture will increase working efficiencies through improved machine control techniques such as sectional control, controlled traffic farming, inter-row seeding and down force control, at the same time as enabling the increased use of autonomous machines to reduce labour requirement.

4. Precision Agriculture and advanced machine control will be critical to fulfil the potential of scientific advances in crop breeding programmes.

5. Data analysis is key to unlocking the full potential of variable rate technology. It has to be good enough to determine the cause of the variation, and not just measure the variation.

6. Data is king - how it is collected, interpreted, utilised and who owns it. Data management has to be simple, intuitive and freely available across all devices, from in cab controllers to a smartphone in a farmer's pocket.

Precision agriculture has to be based on good agronomy.
Precision agriculture will not make a **bad** farmer into a **good** farmer, but can make a **good** farmer into a **better** farmer.

15 - Recommendations

Considering everything I have seen and all the people and businesses I have visited during my Nuffield scholarship I have come up with the following recommendations to the wider UK agricultural industry to increase the benefits and adoption of Precision Agriculture.

1. As an industry we need to move away from "Picture AG to Precision AG". To enable this to happen we need better analytical software to identify the real limiting factor, and quantify the gain.

2. There is a need to develop more remote sensors to improve site specific weed management for a wider range of weeds. Blackgrass is not the only grass weed in the UK.

3. Data transfer between all devices has to be made easier, from controllers and terminals to the office PC, tablet or smartphone.

4. Technology manufacturers need to work towards a common platform based around mobile devices such as smartphones or tablets, to increase compatibility between brands.

16 - After my Nuffield

I have been asked what I am going to do after my Nuffield Scholarship. This is a difficult question because when does a Nuffield Farming Scholarship end? Is it after submitting this report or the presentation at the annual conference? As far as I am concerned it will never end, as I will continue to pursue my desire to learn more about how I can improve what I do and transfer that knowledge to others. I have had the honour and the privilege to meet some amazing people, some of whom will become lifelong friends, and have developed a network of contacts around the world. All these have shared knowledge and experiences with an openness that is refreshing in the agricultural sector.

On the farm we have upgraded our guidance systems to RTK, to benefit from the higher level of accuracy which would be needed in the future for any form of CTF, inter-row seeding or implement steering. We are also working with an aerial imagery company researching the capability of grass weed identification in cereal crops, to enable us to map weeds and target them more accurately.

Having spent time with positive, inspirational people who have been successful, the most important thing Nuffield has given me is the confidence in myself to try different ideas.

Every problem has a solution,
you just have to find it!

17 - Executive summary

As farmers I believe the greatest challenge we face globally is how to feed the world. This is a three pronged problem. Firstly, world population is increasing year on year even though birth rates are decreasing. If it continues to grow at this rate by the end of this century there will be four times as many people to feed compared to 1950. Secondly, diet is changing to one that is more reliant on animal proteins, which requires more food to produce. More than a quarter of all the meat produced worldwide is now eaten in China, consuming nine times as much as in 1978. Thirdly, how do we produce the extra food required in an environmentally and economically sustainable manner?

We utilise many aspects of Precision Agriculture (PA) in our farming businesses in the UK, and I strongly believe that PA will have a significant effect on how we produce more food in the future. Through the implementation of satellite controlled machines and site specific crop treatments, we are able to work more efficiently and productively. We are no longer constrained by the physical boundaries of our fields, and are able to manage fields within fields to maximise the potential of the land at our disposal.

The aim of my investigation was to see how PA is being developed around the world, what techniques can be utilised in the UK, and how we can improve our own farm practice. PA can be split into three different areas, machine control, site specific application and data management. In the USA, the home of GPS (Global Positioning System), I saw how it was being used for advanced machine control including implement steer, inter-row seeding and pulse width modulation sprayer control. I also saw how row crop planters are being adapted to maximise the benefits from advances in GM breeding programs to increase yield. Variable rate applications of water, fertilizer and seed were being used to increase efficiency and productivity in USA, Canada, Australia and New Zealand, taking into account historical potential and real time information. Site specific weed management using optical sensors, either machine mounted or from the air by unmanned aerial vehicles, is targeting herbicides only where necessary to reduce overall use and increasing environmental stewardship.

As my study progressed it became clear to me that PA is perfectly suited to UK agriculture. PA will increase production by targeting inputs more accurately using variable rate applications and advanced machine control, at the same time as improving working efficiency in an economic and environmentally sustainable way. The key ingredient to all PA is data, how it is collected, interpreted, utilised and who owns it? Data management has to be simple, intuitive and freely available across all devices, from in-cab controllers to smartphones in farmers' pockets. To benefit from the full potential of variable rate applications, data analysis has to be good enough to determine the cause of variation not just measure it.

Andrew Williamson

18 - Acknowledgments and Thanks

It would not have been possible to complete my Nuffield without the full support of my wonderful wife Caroline, who was pregnant with Harriet during my visit to North America and had to look after her and our other two children whilst I was away in New Zealand, Australia and Brazil. My sincere thanks must also go to my parents for their encouragement to apply for a Nuffield Farming Scholarship and their support of myself and Caroline during my travels and afterwards, alongside managing the farm in my absence.

I am very grateful to the Nuffield Farming Scholarship Trust for selecting me, and recognising my potential. even though, as most Scholars feel I am sure, I thought I could have done much better in my interview. I would like to thank the past director of the trust, John Stones NSch, for his encouragement and guidance during the application process two years ago, and also current director Mike Vacher for his help over the last two years.

I am very appreciative of the support from my sponsor NFU Mutual Charitable Trust, who made my aspiration to become a Nuffield Farming Scholar possible.

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The list of people below is an indication of how special a Nuffield Farming Scholarship is: to get so many people, whom you have never met before, to give up their time to meet you, feed you and host you, my sincere thanks to you all.

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UK

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Precision Decisions, York
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Dr. Daniel Kindred, Senior Research Scientist, ADAS, Cambridge
Mark Jarman, Operations Manager, Ursula Agriculture, Aberystwyth

19 - Appendices

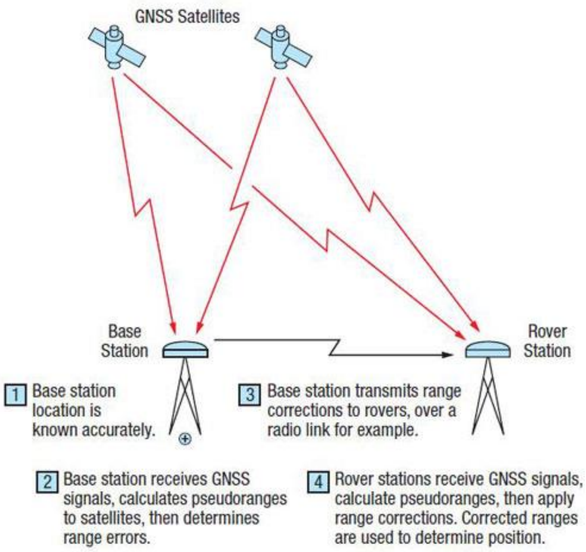
19.1 - Appendix 1 : GPS – the nuts and bolts

The **Global Positioning System** (**GPS**) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. The system provides critical capabilities to military, civil and commercial users around the world. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver.

The GPS project was developed in 1973 to overcome the limitations of previous navigation systems, integrating ideas from several predecessors, including a number of classified engineering design studies from the 1960s. GPS was created and realised by the U.S. Department of Defense, (DoD) and was originally run with 24 satellites. It became fully operational in 1995.

In addition to GPS, other GNSS (Global navigation satellite system) signals are in use or under development. The Russian Global Navigation Satellite System (GLONASS) was developed contemporaneously with GPS, but suffered from incomplete coverage of the globe until the mid-2000s. There is also the planned European Union Galileo positioning system, and Chinese Compass navigation system.

There are 3 different levels of accuracy of GNSS signals, the least accurate signals are freely available and offer accuracy to within 1 metre. This accuracy is perfectly adequate for basic auto steer or "Sat Nav" systems widely used in cars.



Source: google images

The next level of accuracy, DGPS (Differential GPS) uses a correction signal from a fixed base station at a known location. The correction signal is available via a subscription. It will only be accurate to within 10 cm pass-to-pass for a 15 minute period; the inaccuracy is caused by satellite drift. As the signal passes through the atmosphere from the satellite to the receiver on the machine, it will get diverted due to interference, and hence take longer to travel the distance than if it travelled in a straight line. The reference station calculates the distance from the satellites, known as the pseudorange, and calculates the distance error. The error is transmitted to the roving receiver on the machine, which then adjusts its position accordingly.

The highest level of accuracy is RTK (real time kinematic) which is accurate to within 2.5cm and is also the only correction signal that is repeatable, due to the use of fixed local base station. To increase the accuracy of the correction signal, the RTK base station not only calculates the pseudorange of the satellites but also measures the phase of the carrier wave which is unaffected by atmospheric conditions. The RTK base station is located near to the rover and transmits the correction signal via radio link.

Fixed RTK base stations work best in open flat landscapes where the radio signal is uninterrupted. In hilly or more wooded areas the installation of strategically placed repeater stations can overcome this problem by bouncing the correction signal back to the rover when it can't receive the signal direct from the base station. Setting up your own base station and repeaters can be very expensive initially but there isn't an annual subscription fee like DGPS. Alternatives to a fixed base station include a mobile base station, or sending the correction signal from a fixed base station owned by a third party via the mobile phone network instead of a radio link. A mobile base station raises issues with repeatability if it is not accurately positioned in the predetermined known locations, but is less expensive. Sending the correction signal from a third party-owned fixed base station makes it possible to cover a very large and varied area, as long as there is a mobile network connection, without large capital expense, but it does incur an annual subscription fee.

A couple of other points to consider when deciding on the system that is best for your situation. Regardless of how the correction signal is transmitted from the base station to the rover, it will only send the data from the satellites it sees; therefore if the base station only sees GPS but the rover works with GPS and Glonass, only GPS will be used. There are also different messaging protocols for the correction signal, and some systems will only work with their own messaging protocol.

P.T.O. for Appendix 2

19.2 - Appendix 2 - Field headland %age comparison

Field area	Field area	Side length	Headland Width	Headland Area	Headland % of Field
ha	**m2**	**m**	**m**	**m2**	**%**
5	50000	316.00	24	30336.00	60.67
10	100000	316.00	24	30336.00	30.34
12	120000	346.41	24	33255.38	27.71
15	150000	387.30	24	37180.64	24.79
20	200000	447.21	24	42932.51	21.47
25	250000	500.00	24	48000.00	19.20
30	300000	547.72	24	52581.37	17.53
35	350000	591.61	24	56794.37	16.23
40	400000	632.46	25	63245.55	15.81
45	450000	670.82	26	69765.32	15.50
50	500000	707.11	27	76367.53	15.27
55	550000	741.62	28	83061.42	15.10
60	600000	774.60	29	89853.21	14.98
65	650000	806.23	30	96747.09	14.88
70	700000	836.66	31	103745.84	14.82
75	750000	866.03	32	110851.25	14.78
80	800000	894.43	33	118064.39	14.76
85	850000	921.95	34	125385.80	14.75
90	900000	948.68	35	132815.66	14.76
95	950000	974.68	36	140353.84	14.77
100	1000000	1000.00	37	148000.00	14.80
200	2000000	1414.21	38	214960.46	10.75
400	4000000	2000.00	39	312000.00	7.80
800	8000000	2828.43	40	452548.34	5.66