A Nuffield Farming Scholarships Trust

Report

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PRECISION AGRICULTURE:
In the Field and Beyond the Farm Gate.

The Application of Precision Farming Technologies for Rural Land and Asset Management

Davina Fillingham

July 2014

NUFFIELD UK

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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: In the Field and Beyond the Farm Gate. The application of precision farming technologies for rural land and asset management.
Scholar	Davina Fillingham
Sponsor	John Oldacre Foundation
Objectives of Study Tour	The objective of my study tour was to investigate and identify the following: • Precision agriculture technologies that are available to farmers and land managers. • How farmers and land managers can utilise data from precision farming technology • How professional advisors can utilise the data for rural land and asset management.
Countries Visited	UK, France, Spain, Netherlands, Germany, Australia & New Zealand
Findings	• Precision agriculture technologies enable farmers and land managers to quantify variability, consider yield potential and monitor the natural environment to improve practices, adapt and become more efficient; thus addressing the problems presented by a growing population and environmental challenges. • New crop modelling and simulation applications are required as tools to assess the yield potential of land which accounts for changing climatic conditions through a season, and assess the potential return against input costs and environmental impact. • An EU or UK protocol is required that sets out guideline on ownership of farm data and how it is to be managed, and transferred between land occupiers. • Beyond the farm gate the ability to identify and measure factors that affect the productive capacity of land will have an impact on factors such as land values.

CONTENTS

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

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CONTACT DETAILS

Davina Fillingham MRICS FAAV NSch
Gatehouse Farm
Church Lane
Watton
Driffield
East Yorkshire YO25 9AH

Tel:	01377 270074
Mob:	07894 697724
Email:	info@agri-sense.co.uk
Website:	www.agri-sense.co.uk
Twitter:	@Precision_Agri

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Southill Farmhouse, Staple Fitzpaine, Taunton TA3 5SH
Tel : 01460 234012
email : director@nuffieldscholar.org
www.nuffieldscholar.org

1.0 Personal introduction

Having grown up on a small farm in East Yorkshire, I graduated from The Royal Agricultural College Cirencester in 2004 with an honours degree in Rural Land Management. I obtained my professional qualifications with the Royal Institution of Chartered Surveyors (RICS) and Central Association of Agricultural Valuers (CAAV) in 2007, having completed my training with Stephenson & Son, Chartered Surveyors, Auctioneers and Valuers, based at York Auction Centre.

I have since progressed to the position of Associate Partner within the company and am a registered valuer with the RICS. I am also the Vice Chairman of my local East Riding branch of the Central Association of Agricultural Valuers.

My day to day work involves providing agribusiness advice, managing contract farming arrangements, in-hand farming operations, alongside day to day valuation work, land and estate management, farm environment and conservation advice, nutrient management, agricultural planning advice, Single/Basic Payment Scheme and Cross Compliance advice. I am also an auctioneer at York Auction Centre. I have a very diverse job in which I am driven by learning about new agricultural systems and technology.

The author, Davina Fillingham

As a land manager I feel that it is very important to understand the land I am instructed to manage and this includes the natural resources of soils, water and nutrients. In 2012 I completed my BASIS FACTS qualification for nutrient management.

Outside work I have a small flock of 30 pure bred LLeyn ewes which keeps me busy in my spare time as well as being part of York City Rowing Club regularly training on the river Ouse in York.

2.0 Background

I have seen the emergence of precision farming technology and its potential benefits to farming practices and the environment. I know it has an important role to play in future rural land and business management and that is an area of agriculture that will advance significantly over the next ten years together with recent advancements in sensor technologies.

With this in mind I wanted to gain an insight into the various precision farming technologies available and consider how these and geo-referenced data could be integrated to provide more sustainable land management and modernise the way we assess land.

During my day-to-day work I was increasingly visiting farms in the early stages of the adoption of precision agriculture; they had perhaps been collecting yield maps from the combine, but I would often find these had been filed away with no further consideration.

I found it concerning that this data was being obtained on farms but its utilisation and interpretation appeared to be limited despite the potential to use the information to improve farm efficiency.

Obtaining the data is not a problem but the interpretation and application of that data for management is.

Obtaining the data is not a problem but the interpretation and application of that data for management is.

I started my Nuffield Farming Scholarship wanting to answer the following key questions;

- What precision agriculture technologies are available to farmers and land managers
- How can farmers utilise data from precision farming technology
- How can the data be utilised beyond the farm gate for rural land and asset management

I hope that my report will provide a point of reference for people new to the concept of precision agriculture including farmers, land managers and advisors.

3.0 My study tour – where I went and why.

At the start of my Scholarship it was clear that to obtain a real insight into precision agriculture, I would need to travel within the European Union, Australia and New Zealand.

The early part of my study tour took me to the SIMA agricultural machinery exhibition in Paris in February 2013 where, as a guest at the Farming by Satellite award ceremony I met representatives from the European Global Navigation Satellite Systems Agency and Michel Bosco from the European Commission responsible for European Satellite Programmes.

In July 2013 I travelled to Llieda, Spain, for The European Conference of Precision Agriculture. This conference was of particular interest to me as it brought together precision agriculture research projects from around the world and I knew that it would help me to establish contacts for the remainder of my travels.

In October 2013 I visited the Netherlands to learn about the range of Trimble products and see them in action and operate the various technologies myself in practical workshops. I also got to meet Trimble resellers and discuss with them developments in precision agriculture and markets for the range of products in their home countries, which ranged from Russia, Latvia, Denmark and America. I also visited the University of Wageningen to see the broad spectrum of research they were carrying out in precision agriculture.

In November 2013 I travelled to Germany to Agritechnica, the world's largest machinery exhibition, which brought together precision farming companies and technology from across the world.

Following on from that I travelled to Australia and New Zealand covering over 4000 kms by road to visit universities, farmers, Nuffield Farming Scholars and advisors for the remainder of November, arriving home in the UK a week before Christmas 2013.

My study included visits within the UK to establish a greater insight into precision agriculture in the UK including presentations on the use of unmanned aerial vehicles. I also visited Scotland to look at the use of GPS and geographical information systems in forestry.

The European Conference on Precision Agriculture, Lleida, Spain – Field Demonstration Day

4.0 Introduction

Global population is expected to increase from nearly seven billion today to eight billion by 2030, and probably to over nine billion by 2050; competition for land, water and energy will intensify, while the effects of climate change will become increasingly apparent.

The United Nations Food and Agriculture Organisation (FAO) estimated that if current patterns of food consumption persist, 60% more food will need to be produced globally by 2050, compared with 2005-07. In response, agriculture needs to become more productive and efficient in the UK and in the rest of the world.

Overall, relatively little new land has been brought into agriculture in recent decades. Although global crop yields grew by 115% between 1967 and 2007, the area of land in agriculture increased by only 8% and the total currently stands at approximately 4,600 million hectares. Of 11.5 billion hectares of vegetated land on earth, about 24% has undergone human-induced soil degradation, in particular through erosion

The competition for land and the range of users means that land available for agriculture is likely to decrease. With the population continuing to increase farmers must try to produce more food from less land whilst also protecting the environment and carrying out sustainable farming; and all within the context of "sustainable intensification" which the Royal Society describes as a process "in which yields are increased without adverse environmental impact and without the cultivation of more land".

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The report "The best use of UK agricultural land" published in June 2014 states that by 2030 the UK could require up to 7 million hectares of additional land to meet the UK'S need for food, space, and renewable energy. The report - produced by the Cambridge Institute for Sustainability Leadership in collaboration with the NFU and ASDA, Sainsbury's and Nestle - suggests that we need to consider carefully how the land is used. Land will need to be multifunctional delivering a range of goods including ecosystem services, and utilisation of the very best technology and innovation is required to help meet the demands on the land.

Agriculture already currently consumes 70% of total global 'blue water' withdrawals from rivers and aquifers available to humankind. Demand for water for agriculture could rise by over 30% by 2030, while total global water demand could rise by 35–60% between 2000 and 2025, and could double by 2050 owing to pressures from industry, domestic use and the need to maintain environmental flows. A precise approach to irrigation will be needed to meet both economic and environmental constraints.

Agriculture lies at an intersection of two important trends: the need to feed a growing population and the increasing environmental impact of that population. Reconciling these competing pressures is one of the main challenges that agriculture currently faces (*Robertson and Swinton 2005*).

Sustainable land management is an important part of sustainable intensification of agriculture.

4.1 Sustainable land management

Sustainable land management is defined as the use of land resources, including soils, water, animals and plants for the production of goods to meet changing human needs; while simultaneously ensuring the long term productive potential of these resources and the maintenance of their environment functions. (*UN Earth Summit 1992)*

Agriculture lies at an intersection of two important trends: the need to feed a growing population and the increasing environmental impact of that population.

It involves the management of agriculture and the environment through twin objectives:

1. Maintaining long term productivity of the ecosystem functions (land, water, biodiversity), and
2. Increasing productivity (quality, quantity and diversity) of goods and services and particularly safe and healthy food

Sustainable land management is crucial to minimising land degradation, rehabilitating degraded areas and ensuring the optimal use of land resources for the benefit of present and future generations. (*FAO 2014*)

The application of sustainable land management requires involvement at all levels – land users, advisors and policy makers - and balancing the conflicting goals of production and the environment.

Sustainable land management encompasses other established approaches - such as soil and water conservation, natural resource management, plus integrated ecosystem management - and involves a holistic approach to achieving productive and healthy ecosystems by integrating social, economic, physical and biological needs and values.

Precision agriculture provides sustainable farming practices that contribute to sustainable intensification and land management. The ability to determine 'within field' variation and to manage it to improve the economy of agricultural activities and to mitigate their effects on the environment is key to precision agriculture. It offers the prospect of reducing the environmental impacts from farming, as well as improving farm productivity and profitability. *(Bongiovanni and Lowen – De Boer 2004*)

The concepts of precision agriculture and sustainability are inextricably linked.

The concepts of precision agriculture and sustainability are inextricably linked. (*Bongiovanni and Lowenberg – De Boer 2004*)

4.2 Precision agriculture

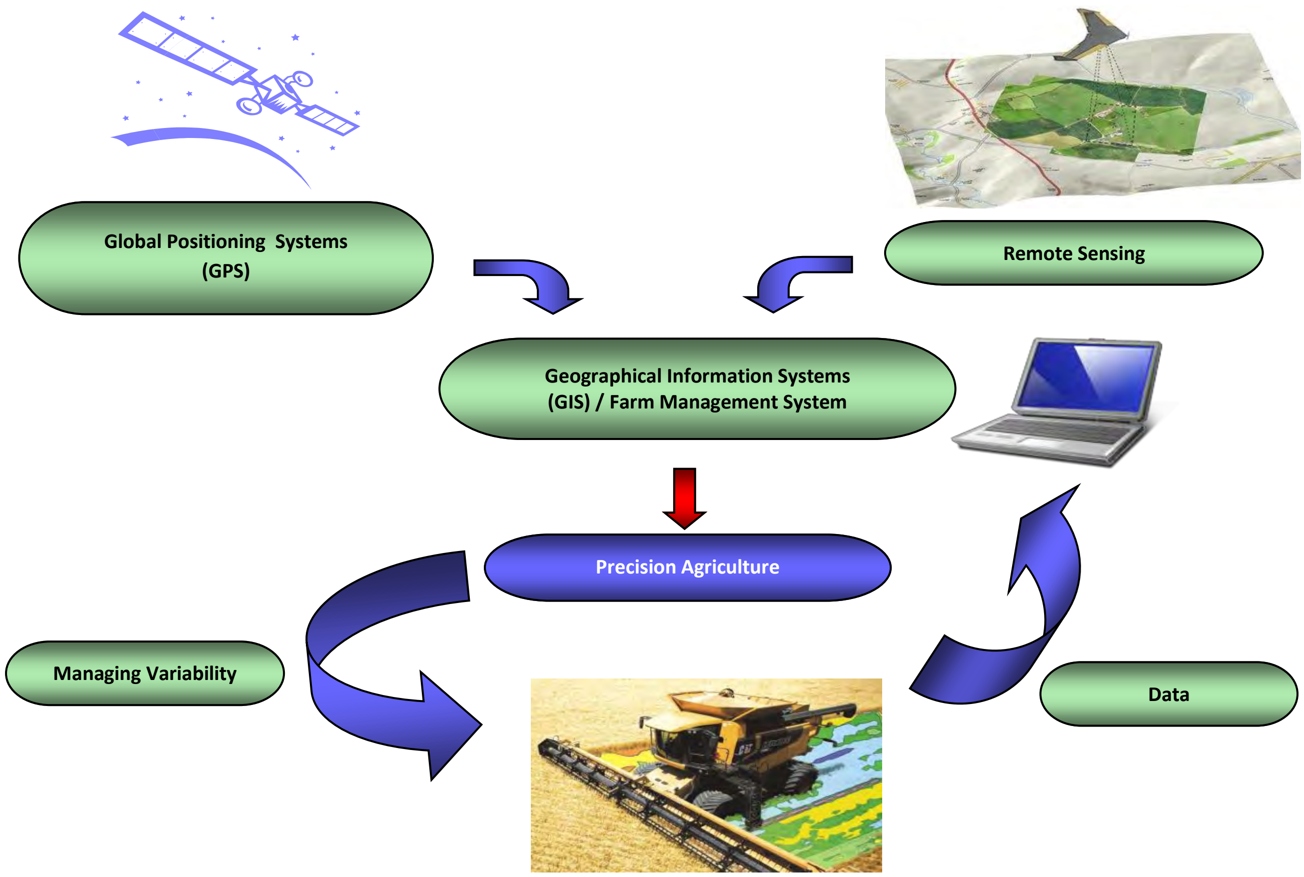
Precision agriculture is the utilisation of three key technologies.

1. **Satellite positioning systems** such as GPS which provides real time information on location.

2. **GIS – Geographical information systems**
   These are Information systems that integrate, store, edit, analyse, share, and display geographic information for informing decision making and management.

3. **Remote sensing** –
   This is the acquisition of information about an object remotely, and generally refers to the use of aerial sensor technologies to detect and classify objects on Earth. Remote sensing in agriculture is normally carried out from satellites or manned or unmanned aerial vehicles.

These technologies are combined to manage spatial or in field variability.



(*Source: D Fillingham 2014*)

Over the last fifty years growers have expanded field sizes by removing fences and hedges, which has increased the variability within fields; and the purchase of bigger, heavier and faster machinery has reduced the accuracy to which variability can be managed. Precision agriculture is nothing new but is a way of managing variability with current field sizes that suits modern farm machinery.

4.3 Variability

Variability in production represents a multi-dimensional problem. It occurs between *years* induced by variation in the weather, within *fields* induced by variation in the soil, drainage conditions, physiology, aspect, salinity, nutrient management, and *across years and within fields* induced by the legacy of management decisions and their interactions with the weather during the growing season. *(J L Hatfield et al 2013)*

Variability can be both spatial and temporal. Spatial variability is the variation within soil, terrain and crop properties across an area at a given time: for example soil pH and crop yield. Temporal variability is the variation found in soil and crop properties within a given area at different measurements in time: for example yield maps from one season to the next.

Practically, variability can be identified by variations in final yield and quality of a crop measured by sensors fitted to harvesters, or by an assessment of biomass throughout a growing season through proximal sensing, machine- or satellite-mounted sensors.

Assessment of variability is not simple. It may not be one specific cause; there are a number of factors that contribute to spatial and temporal variability as follows:

4.3.i Soil

Soil type influences the water holding and nutrient storage capacity of land and as a result influences the yield potential of a crop. The following soil properties are all factors:

4.3.ii Soil structure

Soil structure affects the crop establishment through root growth, soil drainage and water holding capacity of the soil. Damage to soil structure through compaction, waterlogging and loss of soil organic matter can all cause 'in field' variation of crop establishment and development. Soil depth affects the rooting capability of a crop**.** Well-structured soils display high porosity, low density, adequate water storage, free drainage and movement of air within the soil profile. Soil structure affects the physical fertility of the soil in terms of storage of available water and how easily the roots can take up the water; mineralisation of soil organic matter which is affected by temperature, oxygen supply and moisture supply; seed germination and crop establishment; seed and soil contact; temperature and moisture, pest and disease interactions. It affects crop growth including root penetration and extraction of water and nutrients, water holding capacity of the soil, and how easily excess water is shed from the soil.

Spatial variability in soil structure can affect the efficient use of inputs such as fuel and nutrients and contribute to the spatial variability of yield. Spatial variability within soil structure can be detected by using geo-referenced fuel consumption data from tractors when carrying out cultivations, which highlights areas of compaction with increased fuel consumption, assessments based on soil type; or measuring draught resistance in cultivation operations.

Tsiropoulous et al presented a management information system for spatial analysis of tractor implement draft forces at the European Conference on Precision Farming in Llieda 2013. Their research measured draft forces with the aim of utilising data within a farm management information system for optimising tillage operations.

4.3.iii Soil organic matter:-

Organic matter plays an important role in soil structure by binding soil particles and storing and releasing nutrients. Organic matter increases the nutrient holding capacity of soil; increases water holding capacity especially in sandy soils; decreases evaporation; encourages crop root development; improves aggregation, limiting erosion; and compaction damage.

Land management practices have reduced soil organic matter content in many soils. Intensive tillage increases the loss of soil organic carbon by speeding up the decomposition process, whereas practices that increase plant growth in a field - such as cover crops - will increase the amount of roots and residues added to the soil. Organic matter can be measured by optical sensors.

4.3.iv Soil water availability

Water availability is critical to food production. Any limitation in the soil to supply optimum amounts of water at critical growth stages limits plant growth. *(Hatfield and Prueger, 2011)* stated that the shortage of water in some years, with less than adequate rainfall during grain filling, led to a reduction in water use efficiency because of the decreased grain yield induced by water stress. Water stress is a limiting factor in yield potential and can be variable dependent on soil moisture, soil type, elevation and aspect.

4.3.v Soil pH

Soil acidity or alkalinity affects the potential for crops to develop. Most crops prefer a neutral to slightly acidic pH of 6-7. PH can affect the uptake of nutrients by a crop and potentially lock nutrients in the soil;, acidity can restrict crop growth due to increased availability of toxic quantities of aluminium, magnesium and iron. Crops suffering from severe acidity are stunted and chlorotic with thickened branched root systems such as fanged tap root in sugar beet. Problems tend to occur in patches associated with soil type variations.

4.3.vi Soil nutrients

All plants need adequate light, water, carbon dioxide and nutrients to allow them to grow and reach their maximum potential.

Plants take carbon, hydrogen and oxygen from the air; in addition they require 13 other essential elements:-

Nitrogen	**Phosphorus**
Potassium	**Magnesium**
Sulphur	**Calcium**
Boron	**Copper**
Iron	**Manganese**
Molybdenum	**Zinc**
Chlorine	

An excess of an element can cause an imbalance in other nutrients in the plant, which can reduce the yield potential. For example an excess of potassium will reduce magnesium uptake. Variability in soil nutrients can be assessed by soil sampling.

Soil type and structure will lead to variations in soil nutrients within a field.

4.3.vii Elevation and slope

Topography is an important factor within soils. It influences the rate of soil formation, soil erosion, soil moisture and nutrient movement. Changes in elevation control the way water moves or accumulates across and within soil.

Higher elevations are more likely to have thinner top soils and lower elevations may be more susceptible to frost damage. Steep slopes are more susceptible to soil erosion which may be deposited in lower-lying flatter areas of a field.

Elevation is an important factor when considering land drainage and soil protection. Elevation data can be collected to produce a digital elevation model (DEM).

In South Australia I saw the use of computer modelling using digital elevation data to model the likely impact of frost damage within a field. Frost can kill a crop overnight in some regions of Australia, therefore the ability to predict this within a field may affect management decisions.

Digital elevation data in South Australia was used to model the likely impact of frost damage within a field

4.3.viii Aspect

The direction in which land slopes also impacts on the yield potential of a crop. More sunlight is available in the northern hemisphere through a south-facing slope and it will normally be more productive than a north sloping field.

At the CSIRO (Commonwealth Scientific and Industrial Research Organisation) based at Adelaide University, Rob Bramley showed me they have identified that a chemical known as rotundone found in the skins of shiraz grapes provides the peppery taste in Shiraz wine. Research conducted was looking at whether the presence of this chemical was spatially structured. The research found there was a connection with aspect, as the slopes which were further away from north – in a vineyard - produced grape berries containing more rotundone and which were therefore more valuable. The ability to identify spatially the location of the higher quality produce would mean that the grape berries could be kept separately and marketed as a premium product. At the time of my visit the price difference between a standard bottle and a higher quality Shiraz with a more peppery taste was around 12 dollars a bottle. It is likely that aspect affects quality in a range of commodities; however no one may yet have asked the question how.

4.3.ix Pests and diseases

It can be harder to find a spatial reason for insect damage in a crop but in some cases it may be linked to soil type, soil conditions or the health of the crop, and it is therefore important to understand the spatial variability of those factors. One example of this I saw on my travels was the mapping of paddock zones prone to redheaded cockchafer (RHC) infestations. RHC is a pest of improved pasture in south eastern Australia and is currently detected by the human eye through visible pasture damage. The research was carried out by Amy Crosby of The University of New England, Armidale, and was presented at the European Conference of Precision Agriculture in 2013.

Potato cyst nematode (PCN) can be mapped by testing geo-referenced individual field samples to map high risk areas and apply treatment accordingly.

Weeds will often develop in patches. For example, blackgrass will start to develop in patches and spread. The patches can be spatially mapped using handheld GPS, marked on in-cab GPS displays when carrying out field operations, or identified using remote sensing. This will allow for target treatment rather than blanket treatment.

The impact of crop disease can again be difficult to map spatially and depends on the type of disease. Crop infection can often be determined by biomass crop and mapped for site specific treatment.

4.3.x Previous management / land use

Past management or uses of the land has an important role to play. It may not be mapped but an individual person's historic knowledge can be very important in determining variability. For example former WW2 airfields which have been returned to production may find yield potential affected where there have been fuel storages, fuel spillages, runways etc.

A farmer's profit is not always dependent on the highest yield but, in order to be sustainable, farmers and land managers need to maintain a balance between the cost of production and attainable yield.

On the next page is shown a diagram of satellite imagery taken from a former airfield and highlighting variations in crop establishment on former WW2 runways in East Yorkshire. *Source: Google Earth*

Satellite Imagery from a former airfield highlighting variations in crop establishment on former WW2 runways in East Yorkshire. *Source: Google Earth*

5.0 Precision Agriculture technologies

5.1 Positioning

5.1.i Satellite based navigation systems

Precision agriculture is made possible with satellite based navigation systems that provide geo spatial positioning on or near the earth's surface; otherwise known as global navigation satellite system (GNSS). These systems provide the ability to identify any location on the earth's surface and enables agricultural and environmental operations to be geo-referenced and spatially analysed. Commonly referred to as GPS, GPS actually refers to the US Navstar global positioning system satellites controlled by the US Department of Defence. There is also the Russian system Global'naya Navigatsionnaya Sputnikovaya (GLONASS). These systems were launched towards the end of the cold war and were designed primarily for military use, being adapted in later years for civilian use. These systems are referred to as GNSS-1 systems.

New systems designed for civilian use are referred to as GNSS-2. One example of this type of system is the EU GALLILEO system. This system is inter-operable with US GPS and the Russian GLONASS system and currently has 4 operating satellites out of an anticipated 30. The system hopes to provide accuracy to 1m once fully operational.

GNSS-1 systems require a differential correction signal to provide improved accuracy to civilian users ,whereas GNSS-2 systems have an increased accuracy without the need for a differential signal. NAVSTAR GPS have, however, recently been overhauled to improve accuracy. These systems are all free signals.

Each system consists of a constellation of 20-30 orbiting satellites which transmit signals with location & time. GPS receivers receive these signals from satellites and calculate their position in three dimensions.

5.1.ii Types of receivers and signal correction

The accuracy of the GPS depends on type of receiver. Stand-alone GPS receivers operate with no external correction, and they are typically suitable for low accuracy requirements such as wide swath harvesting, and low resolution uses such as yield monitoring. The standardised accuracy provided is 6-10m when stationary.

Real time differential GPS (DGPS) receivers require two antennae: one to collect the signal from the GPS satellites and another to receive the correction signal.

The correction signal can come from different sources providing different levels of accuracy, one example of which is a base station. A local base station with a second GPS receiver and a pair of radios to transmit and receive a correction signal will provide a real time kinematic (RTK) correction signal. Single base stations are limited to a range of approximately 30km, depending on any terrain interference. RTK is recognised to provide an accuracy of +/-2 cm.

A stand-alone base station

Issues regarding the range of a base station can be overcome by providing a base station network. Of the farmers I visited, a number allowed base stations to be located on their land and in return would receive a free correction signal.

Mark Branson – Australia, with a networked base station located on his land

EGNOS is a correction service for GPS and comprises of 3 geostationary satellites and a network of ground stations and allows users to determine their position to within 1.5 m accuracy. The EGNOS service has been operational since 2009 and is freely available to anyone equipped with an EGNOS enabled GPS receiver. EGNOS provides a pass-to-pass accuracy of +/-20cm.

Other correction services include the EGNOS Open Service which has been available since 01 October 2009. EGNOS positioning data are freely available in Europe through satellite signals to anyone equipped with an EGNOS-enabled GPS receiver.

Correction Services	Accuracy	Description
CenterPoint RTK	< 2.5 cm	RTK base station coverage
CenterPoint VRS	< 2.5 cm	Mobile Phone signal (USA, Europe)
CenterPoint RTX	4 cm	Mobile Phone Signal (Worldwide)
OmniSTAR HP	5-10 cm	Satellite Correction (Most of World)
OmniSTAR G2	8-10 cm	Satellite Correction (Worldwide)
OmniSTAR XP	8-10 cm	Satellite Correction (Worldwide)
OmniSTAR VBS	15-20 cm	Satellite Correction (Most of World)
SBAS (WAAS, EGNOS, MSAS)	15-20 cm	Satellite Correction (USA, Europe, Japan)

Source Trimble 2014 (Accuracy shown as Pass-to-pass Accuracy)

John Deere operates two correction services, Starfire 1 and Starfire 2. Starfire 1 provides a positional absolute accuracy of 1m with a pass-to-pass accuracy of 15 to 30cm, while Starfire 2 provides an absolute accuracy of 4.5cm with a pass-to-pass accuracy of 10cm. RTK can be used to increase accuracy down to 2.5cm.

When choosing correction signals the pass-to-pass accuracy and absolute accuracy must be considered. The pass-to-pass accuracy considers how close you are to the last pass, typically from a moving vehicle over 15 to 20 minutes. Absolute accuracy is the static accuracy connected to how close you are to the same point the next week, month or year.

RTK uses either radio or cellular communications to provide correction signals.

When using RTK with radio communications, you need access to a base station located within a seven-mile radius (approximately) from your farm. An RTK base station sends corrections via a radio transmitter to the mobile receivers attached to your vehicle. Base stations can be purchased for individual farming operations, or utilised through a subscription service from an established network.

Trimble xFill technology utilises Trimble RTX technology, delivered via satellite, to "fill in" for RTK corrections in the event of temporary radio or Internet connection outages, which are the primary sources of dropped corrections. This provides more in-field run time with fewer interruptions.

A cellular communication modem may also be used instead of a radio to provide RTK corrections. These cellular networks are referred to as continuously operating reference stations (CORS). CORS uses a single GPS/GNSS reference station to transmit RTK corrections to the cellular modem on a tractor. This reference station may be located a long distance from the grower's modem, making it a popular option in areas with spotty RTK radio tower coverage.

Satellite based navigation systems underpin precision agriculture providing geo-referenced information and data. It supports positioning and auto steer systems

Using geographical information systems (GIS) we can bring together data from a number of sources such as aerial photography, hard-copy maps and GPS surveys. GIS gives you the power to visualise, explore, interpret, query, and analyse geographical data and so provide support for making informed decisions

5.1.iii. Machine guidance and auto steer.

GNSS signals are used to guide tractor operators or control steering using either a steering assist system or integrated auto steer system.

Operator guidance displays the location of the vehicle on a screen in relation to the desired route to enable its operator to steer as accurately as possible along the guided route. There is no machine control over the steering. Steering assist systems involve an attachment of a device to the machine steering wheel, which effectively steers the machine.

Integrated auto steer systems connect directly with the machines' steering systems through electric control of in-line hydraulic valves to actively control steering. Use of integrated steering control with RTK correction provides the most accurate auto steer system.

5.1.iv. Implement guidance

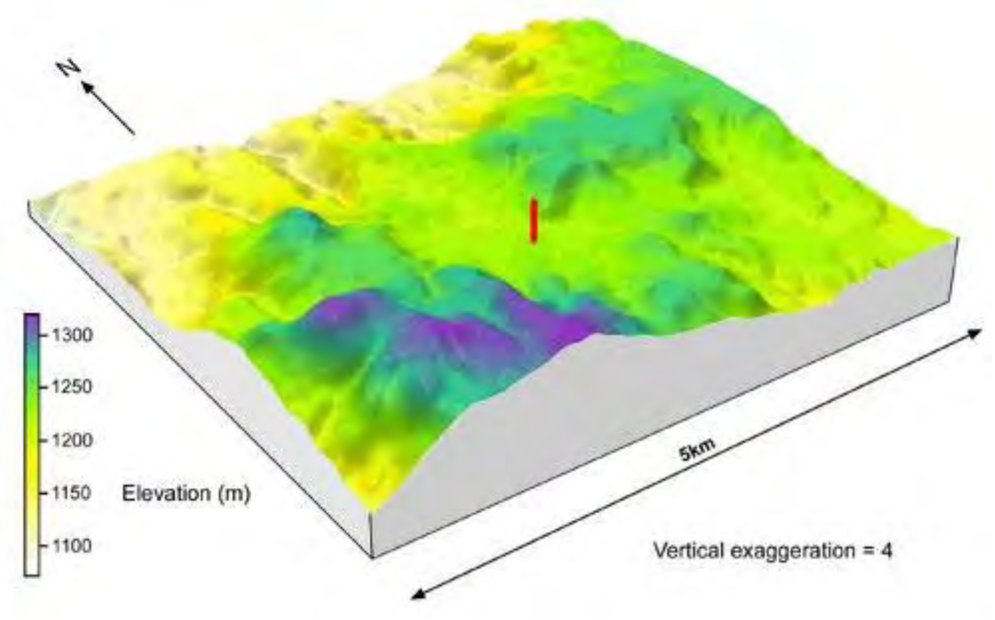
With the installation of a GNSS antenna on implements and integrated auto steer on a tractor, systems are available that are designed to maintain implement accuracy and minimise overlaps and misses in rolling terrain or rough ground where implement precision is essential: for example seeding. The systems concentrate on maintaining the accuracy of the implement either by compensating steering through auto steer on the tractor or by working independently of the tractor with control systems fitted to the implement.

The table below demonstrates the range of operations suitable for each level of accuracy.

Operation	Stand Alone GPS	DGPS	RTK
Yield Mapping	X	X	X
Soil Mapping/ zoning	X	X	X
Crop Scouting	X	X	X
Cultivations	X	X	X
Variable Rate Applications		X	X
Spraying		X	X
Fertilizer applications		X	X
Seeding		X	X
Machine/ implement Guidance		X	X
Machine/ implement Auto Steer			X
Field Boundary Mapping			X
Elevation Mapping			X
Land Levelling			X

5.2 Elevation

GNSS receivers can also determine elevation. RTK-enabled receivers provide the most reliable accuracy for elevation data, and provide affordable elevation data which can be collected easily from agricultural vehicles fitted with auto guidance systems.



Digital Elevation Model (*Source: Ozflux 2014*)

In my opinion, elevation is one of the most under used forms of data in precision agriculture but also one of the most important. In Section 4.3.vii I have considered why elevation slope and aspect are important. The data collected from the machinery fitted with guidance can be used to produce a digital elevation model (DEM) which provides a digital model of a terrain surface, as shown in the picture above.

> *In my opinion, elevation is one of the most under used forms of data in precision agriculture but also one of the most important.*

The data can also be used to produce depression maps which will highlight where water will be stagnant, which will typically cause yield losses due to waterlogging.

This data can also be taken a stage further to identify possible drainage schemes. Trimble's surface software allows for the interpretation of elevation data to model and cost drainage systems. The design for a scheme can be exported to drainage contractors' machines which are fitted with GPS, to be laid as modelled. Mastenbroek fit their machines with Trimble systems, which can utilise modelled drainage plans to lay the drainage scheme exactly as planned. Final as-laid digital plans can also be produced which can be uploaded into farm management systems.

See photo on next page.

Land Drainage (*Source: Mastenbroek 2014)*

During my visit to the Netherlands, I saw land levelling being carried out; again this uses elevation data to level the land according to a specification designed with the surface software. Land levelling is not commonly used in the UK, but is used in the Netherlands, Australia and New Zealand for water management.

5.3 Soil surveys

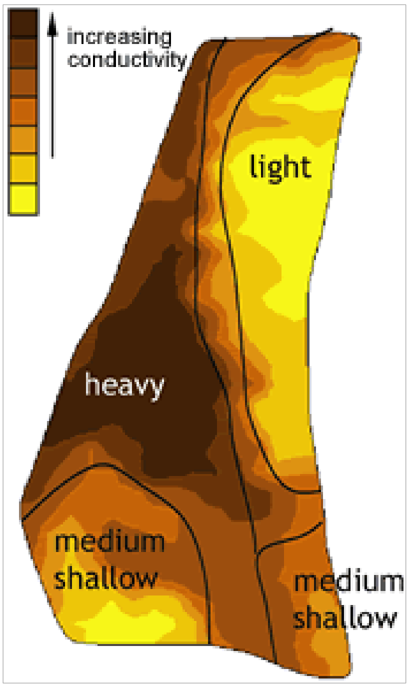
Soil is one of the primary causes for variability of crop performance. As yield maps now provide an insight into the variability that exists, a more detailed picture of the soil is required to help understand that variability.

Soil sampling on the traditional 'W' sample method does not provide the level of detail to manage 'in field' variability effectively and improve efficiency.

Geo-referenced grid sampling using 1 ha blocks provides a coarse scale of soil variability.

Soil variability can be measured and mapped using electrical conductivity sensors which can be used to identify soil zones, which can then be sampled and tested to create field soil maps.

See an electro conductivity soil survey results map, identifying soil zones, on next page.



Electro conductivity soil survey results map identifying soil zones. Source: Soyl 2014

5.3.i. Electro conductivity testing

Soil electro conductivity is influenced by the combined relationship between, clay content, clay type, soil water and soil salinity. In principle the higher the electrical conductivity the higher the yield potential and fertility; however extremely high readings can demonstrate salinity.

Electro conductivity can be measured two ways:

- Electro magnetic induction (EMI)
- Electrical resistivity (ER)

EMI uses paired transmitter and receiver induction coils. A transmitting coil generates a primary magnetic field that produces eddy currents (swirling electrical currents) in the soil. The eddy currents induce a secondary magnetic field that is detected by the receiving coil. The amount of current running through the soil is proportional to the strength of the secondary magnetic field and therefore allows the electro conductivity of the soil to be measured.

The distance between the transmitting and receiving coil on the implement determines the depth to which the current penetrates the soil and this is referred to as the depth of exploration (DOE).

EMI surveys are non-invasive and can be used for vehicle mounted or towed surveys. EMI instruments include EM38 instruments manufactured by Geonics Ltd or DUALEM, each with individual models varying the depth of exploration and number of measurements. EMI surveys are unique and relevant only to the site and time of collection. Regular calibration is required against soil samples.

EMI surveys are normally carried out at two depths: for example 0.5 (shallow) and 1.5m (deep) which can be mapped separately. They provide useful information on variations in soil profile.

Electrical resistivity measurements involve an invasive survey where a metal electrode passes a known electrical current into the soil. A non-active electrode then detects the remaining current; the difference between the applied and received current is the electrical resistivity. The distance between the two electrodes affects the DOE. In Australia a Veris ER is the only equipment available for carrying out trailed ER surveys

Comparison of yield maps and electro conductivity demonstrates that there is a strong correlation of electro conductivity variation and yield variation. For example a higher electro conductivity reading should have a higher yield potential.

Electro conductivity readings need to be taken when the soil moisture content is relatively full as this will provide a much more accurate identification in the variation of soil type. As clay content increases soils become more capable of storing moisture and nutrients.

Electro conductivity testing provides a valuable tool for assessing soil variation and helping to create soil maps which can be used with other data to investigate 'in field' variability.

5.3.ii Gamma radiometrics

Gamma radiation is a high frequency electromagnetic radiation which is used to measure natural gamma ray emissions from the top 40cm of soil or rock. It is used to assist in identifying variations in soil types symptomatic of soil forming processes and soil parent material. Gamma radiometrics assesses the three major elements in the soil that emit gamma rays as they decay;

- Potassium (K)
- Uranium (U)
- Thorium (TH)

Gamma radiometers are very effective when used in conjunction with EMI surveys,

Gamma radiometers provide a much better differentiation between gravel and sand compared to electro conductivity testing. In shallow soils it is more responsive to the parent material and different soil properties.

In Western Australia the combined use of EMI surveys and radiometrics is a preferable form of soil surveying where there are widespread sandy and gravel duplex soils. In areas of low electro conductivity gamma radiometrics is used to distinguish between deep sand and gravel profiles, and in areas of high conductivity can be used to distinguish between clay profiles and saline soils.

Gamma radiometrics can be used on the ground or remotely as gamma rays travel a reasonable distance in the air.

When interpreting gamma radiometrics the landscape and soil formation processes need to be taken into account. Ideally the soil should be dry at the time of the survey.

Both EMI and gamma radiometric surveys only need to be carried out once to provide a soil variability map.

5.3.iii ‘’On-the-go’’ soil sensing

Commercial platforms for measuring a number of soil properties ‘on-the-go’ are currently not available but at Cranfield University platforms which can be used to identify multiple soil properties ‘’on-the-go’’ during normal field operations are being investigated.

The platform shown in the picture below consists of a load cell to measure subsoiler draught; a wheel gauge to measure depth; a visible and near infra-red spectrophotometer for measurement of moisture content, organic carbon, plasticity and bulk density, using pre designed calibration models. The platform is capable of taking 1500 readings per hectare.

Soil sensing (*Source* : *Farming Truth (June 2014)*

The final commercial system will be a web based portal that would allow end users (farmers, growers, etc.) to manage data upload and storage, then to select appropriate "rules" for their specific location and chosen crop using science-based decisions. The resulting treatment maps would then be uploaded to precision-agriculture-compatible implements for application of inputs at the appropriate variable rate or depth when considering cultivations.

5.4 Remote sensing and optical sensing

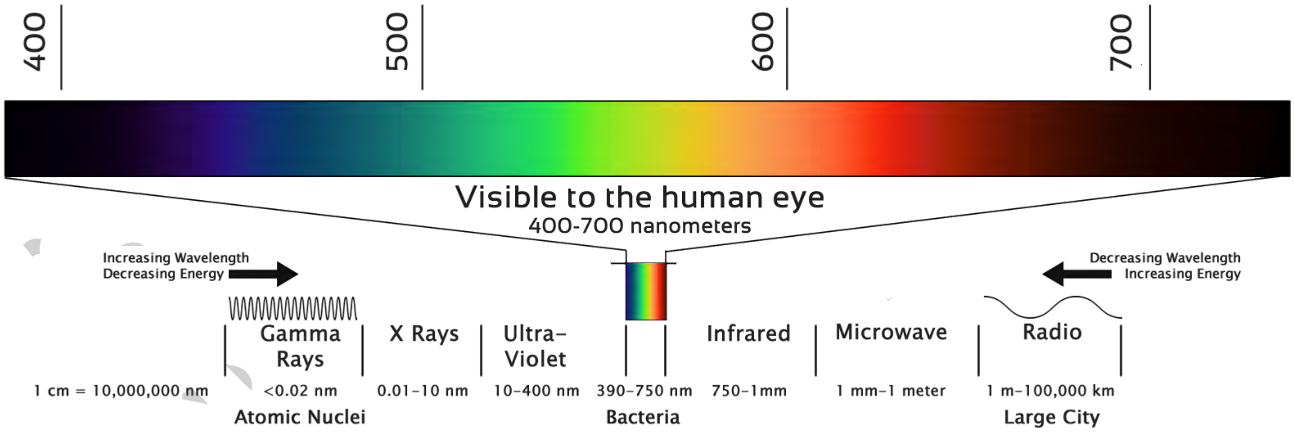
Remote sensing relates to the collection of data from airborne platforms such as satellite unmanned aerial vehicles, or planes. The data and imagery collected can be used to map field boundaries, watercourses and land use; and data collected from the airborne platform can be used to record spatial variability in soils and crops using optical sensing.

5.4.i Optical sensing

Optical sensing can be provided remotely using satellite and aerial imagery. These are forms of remote sensing, or using optical sensors on ground based vehicles which is referred to as proximal sensing.

Optical sensing is used within agriculture to measure variability within soil and vegetation and uses the visible, Near Infra-Red (NIR) and thermal portions of the electromagnetic spectrum.

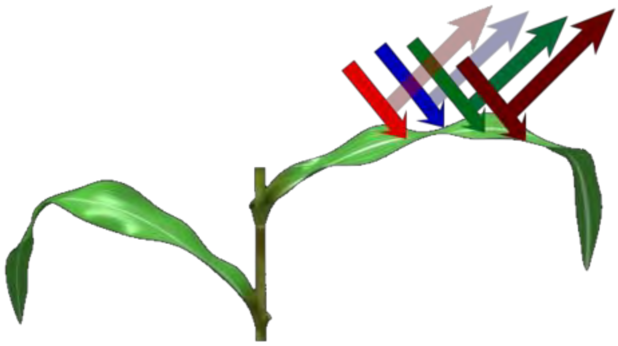
In precision agriculture the most common bands used are the red and NIR bands as the reflectance of these wavelengths can be correlated to plant physiology.



Title : Electro Magnetic Spectrum (sstsoftware 2014)

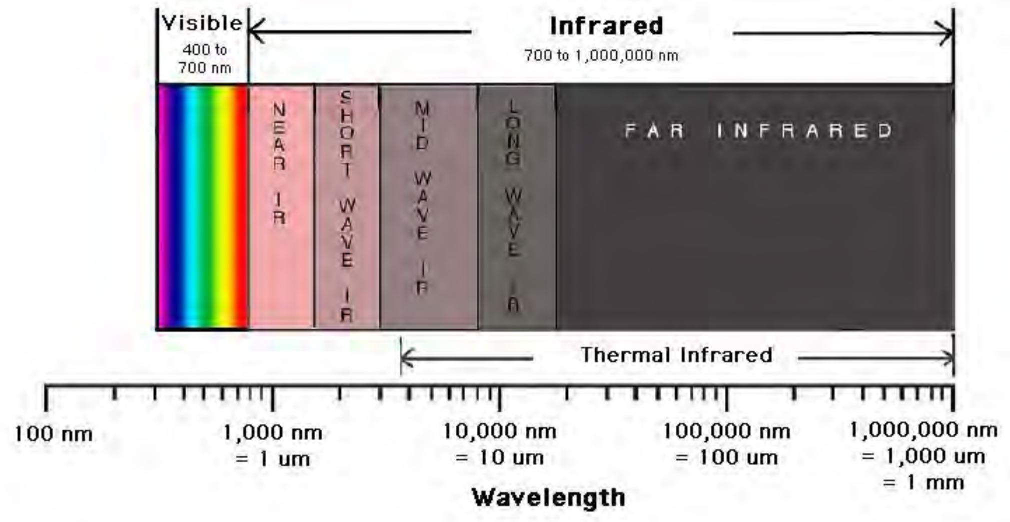
In healthy actively growing plants blue light and red light from the visible spectrum are strongly absorbed by the plant chlorophyll pigment inside the leaf cell chloroplasts, to provide energy for photosynthesis.

All healthy plants reflect more green light, and less blue and red light as they are absorbed by the plant, as illustrated below.



Near Infra Red Reflectance

Near Infra Red Light (NIR) meanwhile is strongly reflected in healthy actively growing plants. Therefore healthy plants display a low red light but high NIR reflectance. Plants under stress will absorb less red light as the chlorophyll activity decreases causing a decrease in NIR reflectance.



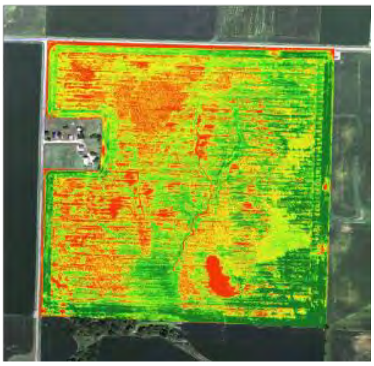
Title : Infrared and visible element of the electromagnetic spectrum

(Source: http://dew.globalsystemsscience.org/key-messages/near-infrared-and-the-electromagnetic-spectrum 2014

Ratios are used to exploit the difference between red reflectance and NIR to assess plant health and nutrient status; for example Normalised Difference Vegetation Index (NDVI). This ratio creates a single picture where the higher the value in each pixel, the greater the health vigour and greenness of the crop. Ground calibration is an essential part of the use of optical sensors/imagery

True Colour

Near Infra red



NDVI

Image to show difference between True colour NIR and NDVI maps (*Source: sstsoftware 2014)*

5.4.ii Platforms for optical sensing

Satellite imagery can provide data for anywhere on the planet. High resolution imagery such as that from rapid eye may have a resolution of 1–5m, moderate resolution imagery such as that from Landsat provides a resolution of 10–30m, and coarse imagery such as that from Modis provides a resolution of between 100m–1km. Satellite imagery can often be affected by cloud cover which is a common problem in New Zealand, plus long revisit times with no ability to control the date of the imagery provided, which does not help if you are assessing crop development. With the development of newer systems, revisit times have reduced down to one day which makes it useful for real time crop monitoring. Soyl UK, at the time of writing this report, provided regular satellite imagery throughout the growing season on a subscription basis for £7 per ha.

Airborne imagery using aircraft platforms including unmanned aerial vehicles (UAVs) can provide imagery on demand. Data can be collected at resolutions of between 25cm to 3m and is less likely to be disadvantaged by atmospheric conditions. The disadvantages of airborne imagery are that they are a less stable platform than satellites, and coverage of large areas may be difficult. In the case of UAVs they may have insufficient battery power to cover large areas and they must stay within range of the operators. Aerial imagery from planes can cost as little as £1 per ha, UAV imagery cost is in the region of £10 per ha.

URSULA (UAS Remote Sensing for Use in Land Applications)

Project URSULA was a research and development programme funded by the Welsh Assembly Government to explore the potential for advanced remote sensing in land applications, primarily in high input arable farming. The project is now a commercial venture which combines remote sensing on an unmanned aerial vehicle, utilising optical sensing technology, with mapping on a geographical information system to provide targeted information on crop performance including:

- Crop damage
- Crop cover and density
- Emergence
- Crop maturity
- Crop damage
- Soil compaction
- Identification of weeds e.g. blackgrass for optimised agro chemical application
- Compliance with agri-environment and subsidy schemes
- Topographical site surveys to provide digital elevation models
- Yield estimates
- Crop trial monitoring

URSULA commercially has collected 1.4 million hectares of data and has developed their own image processing systems and algorithms to provide a broad range of services. Agrovista is using URSULA imagery to monitor blackgrass trial sites at Lamport plus yield potential of the trial sites.

See photo on next page

As well as being collected from a fixed point, reflectance values can be collected using ‘‘on the go’’ optical sensors which are designed to collect reflectance of the crop or soil whilst carrying out operations in the field.

URSULA Unmanned Aerial Vehicle (Source: URSULA 2013)

5.4.iii Real time optical sensors

The sensors described below measure variability and allow an appropriate variable rate treatment to be undertaken in real time and use the principles of optical sensing described in 5.4.i.

5.4.iii.1 N sensor

The N sensor from Yara is designed to assess changing nitrogen requirements during a season - for variable rate fertiliser applications or variable rate growth regulator applications.

The collected information can either be used for variable rate applications ''on the go'', or variable rate applications following assessment of collected data in the office against other variables.

When in operation the Yara N Sensor system applies more nitrogen fertiliser to areas of the crop where the biomass index highlights the nitrogen uptake of the crop is at its lowest. Where biomass is extremely low as a result of external influences other than nitrogen, fertiliser application is reduced. The settings for controlling parameters for rate control can be adjusted by the operator.

Where the system is used for variable rate growth regulator applications, the system will apply more pre growth regulator (PGR) to areas with a high biomass index, and less growth regulator to areas with a lower biomass. This obviously applies growth regulator to the areas of the crop where it is required and does not limit the growth of areas where it is not required - which would be the case if PGR was applied at a uniform rate.

YARA N Sensor

Other sensors used to determine in-season nitrogen requirements for variable rate nitrogen applications include:

- Crop Spec - Topcon
- Crop Circle - Holland Scientific
- Greenseeker - Trimble
- Isaria – Fritzmeier (also distributed by Claas) The Isaria uses fluorescence

Isaria Fritzmeier

Optical sensors are also used for variable rate herbicide use on fallow land. The Weedseeker sensor from Trimble uses the reflectance of red and infrared light to differentiate between bare soil and dead plants and living plants. The sensor identifies weeds and activates sections of a boom to spray the weeds for variable rate herbicide application.

5.4.iii.2 Agricon sensors

At Agritechnica 2013 in Hannover, Agricon launched their range of sensors for precision agriculture. These included the P3 sensor and H sensor.

The P3 sensor is an ultrasonic optical sensor used for crop biomass assessments which can be used ‘‘on the go’’ or to collect information for future variable rate fungicide applications, growth regulator applications and variable rate desiccation.

The H (Herbicide) sensor is a camera-based sensor which uses imagery to distinguish broadleaved and grass weeds, crops and grass. Agricon are building up classification systems for various crop types in order to provide targeted herbicide applications and increase the efficiency of applications. The aim of the sensor is not to identify individual weeds but patches of weeds for treatment.

The sensor can capture the weed image and determine weed distribution within 200 milli seconds. The sensor is mounted on the front of a sprayer boom with normally one sensor per section. The sensors are mounted on an arm approximately 75cm in front of the spray nozzles which allows travel of up to 12km per hour. The further in front they are mounted the faster the operation can be carried out.

In crop trials the sensor accurately identified blackgrass between 80 and 90 per cent of the time. Other trials where broadleaved weeds were found to be present in 72% of a crop of millet showed that the H Sensor could reduce herbicide inputs by 35%.

Hermann Leithold from Agricon spoke at the 16th Symposium on Precision Agriculture held in Australia in advance of my visit, and his presentation had created a lot of interest. It has now been taken up as a research project by the Grains Research & Development Corporation (GRDC) to assess its potential use in Australia. Whilst there have been sensors such as the Trimble Greenseeker available for herbicide applications, the Greenseeker only identifies weeds on a brown background, not on a green background such as in a cropped environment. The H Sensor is the first commercial sensor of this kind to identify grass and broadleaved weeds.

Agricon's P3 sensor

Agricon's H sensor

5.5 Thermal imagery

At the European Conference on Precision Agriculture I saw the use of thermal imagery within a vineyard. Thermal infrared radiation indicates canopy temperature and indirectly the ability of the crop to regulate its temperature by transpiration.

Lack of soil water, rooting limitations or disease can cause canopy temperature to increase. A field demonstration at the European Conference on Precision Agriculture, used thermal imagery mapping by plane to detect plant stress remotely to provide variable rate irrigation within the vineyard. Handheld sensors were used within the field to identify plant stress.

Thermal imagery can be an important tool for monitoring crop health and maintaining yield potential.

Thermal image sensor

5.6 Fluorescence

Chlorophyll in plant cells generates fluorescence in response to light energy received. Approximately 3% of incoming light energy is emitted from the canopy as fluorescence; however, large fluorescence emissions indicate an ineffective photosynthesis process in a plant.

Flavonol and Anthocyantns, known as polyphenols, emit fluorescence. Normally as chlorophyll content falls, due to plant stress, the content of these other molecules rises. This relationship can be used to assess crop nitrogen status.

The Fritzmeier crop sensor uses fluorescence to determine in-season nitrogen requirements.

At the European Conference on Precision Agriculture, Force A, a French company, demonstrated the use of their latest fluorescence sensors for assessing crop quality and managing variability.

The Dualex sensor, manufactured by Force A in France, measures flavonol and the chlorophyll contents of leaves during the heading and flowering stages to forecast protein content of potential bread wheat harvest. It is also used for top dressing recommendations.


Dualex Sensor (*Source: Force A 2014)*

Fluorescence-based sensors appear to be highly sensitive to plant nitrogen status without influence from soil, leaf area or biomass (*Tremblay 2014)*

Force A MULTIPLEX sensors use fluorescence to measure the maturity of grapes by measuring the anthocyanin content of dark grape clusters. These measurements work out a colour index, which allows you to monitor the phenolic maturity of the vineyard. The current demand from consumers in terms of ideal red wine characteristics, are wines with a dark red color, full body, soft tannins, and ripe fruit flavours and aromas. In order to create wines with these types of characteristics, winemakers need to use fully ripened grapes, specifically those grapes that have reached “phenolic maturity”. The multiplex sensor shown on next page can be used to map crop maturity and also be used on a harvester for load separation of harvested grapes depending on maturity. Variation in grape maturity can affect the quality of the wine. The sensor can also be used to estimate the best vintage date for the wine.

Fluorescence can also be used in viticulture to detect downy mildew before visual symptoms appear, which enables more timely fungicide applications.

5.7 Yield mapping

Most current combine models are being sold with some form of yield monitoring system. Utilising GPS to track location, they include sensors to monitor grain throughput, grain moisture content, and grain losses.

Using location data from the GPS this information can be displayed ‘on the go’ in the machine and recorded on a data storage device to upload into a farm management software system to be viewed as a yield map at a later date.

Yield monitors record enough information to calculate yield at each measurement location provided by GPS, as well as elevation data and grain moisture content. Data such as crop type and field can be input by the operator prior to the start of combining in that field.

During my travels I learnt that yield maps provide an excellent oversight of variation within a field and its productivity. They provide a base to investigate the cause for variability which could be as simple as shade from woodland or pest damage - which can be advised upon by the farmer - or nutrient deficiency which requires more detailed investigation.

Multiplex sensor

Care needs to be taken when utilising yield maps for variable rate applications for future crops as there is a ‘flip flop’ effect when yields may vary from one year to the next.

The accuracy of a yield monitor is determined by the calibration of the machine and the width of the header. The wider the header the lower the data resolution is, but this is not to say that it is not representational. Operators need to regularly calibrate the machines to provide representational information and the use of auto guidance steering systems assists in making full use of the header width and providing more accurate yield data.

Yield mapping

Yield data direct from a combine often contains erroneous reference points and needs to be cleaned. This can either be done through farm management software or by a professional prior to further interpretation of the data.

Yield data can be used for:

- Analysis of yield variation
- Creation of management zones
- Generating profit maps
- Estimation of yield potential for future cropping
- Estimating nutrient removal from a field
- Multi season analysis
- Analysis of on farm trials
- Farm conservation

Yield mapping provides the result, not the equation to get to the result; therefore further investigation is required into the causes of variability5.8 Protein meters

Protein meters use optical sensors to measure the protein content of a crop ‘’on the go’’ whilst it is being harvested.

When I visited Ashley Wakefield on the York Peninsula, South Australia, he had a protein meter fitted to his combine. Protein sensors are one of the few sensors that can be used to assess crop quality as well as assessing how successful the nutrient management of a crop had been.

It was clear from our discussions that it would be possible to use a protein meter as a decision making tool for crop marketing. ‘’On the go’’ protein meter readings could be used to make decisions on load separations and marketing quality information. The main driver for Ashley in using a protein meter was for sorting the higher protein content wheat for feeding his pigs.

The separation of higher and lower protein contents also meant that he could blend his own wheat on the farm to improve the average protein content for marketing, giving him more control over outgoing produce quality and achieving the highest possible price.

A Protein Meter Fitted to a Combine

Maps displaying protein variability within harvested grains in a field can highlight areas where there may be variation in nitrogen availability or water availability within a field.

5.9 Optical sensors: summary

Optical sensors look at the external appearance of the crop but not at the actual internal wellbeing of a crop. For example there can be 1001 reasons why plants may not be green, so other types of sensors are required within a crop canopy to determine the status of the crop. These can be chemical sensors for perhaps quality detection in fruit, or biological sensors for detecting disease.

A plant affected by disease firstly has its internal chemistry and biology affected, then later the physical appearance of the plant – such as colour - will change. Biological sensors will allow earlier treatment and opportunity to stop emerging diseases.

Ernest & Julio Gallo Winery of California is testing the use of a microsensor inside vines to monitor water stress. Excess water affects quality negatively, but a controlled amount of water stress provides a sweeter, higher quality grape. The chips provide a greater degree of control over the water requirements of vines and grape quality.

Real Time ‘’on the go’ sensing will need to be used carefully as these technologies often rely on the fact that one variant may affect a crop but, as seen from earlier sections, the number of variants is vast. It can often be better to sit down and consider the data collected in previous passes, then use the information to create variable rate application maps. All sensors will require some form of calibration before use.

5.10 LIDAR

Light detection and ranging (LiDAR) is a technology that uses laser pulses to generate a 3D image of the physical layout of terrain and landscape features.

The LiDAR instrument fires rapid pulses of light (laser pulses) at the landscape, and a sensor mounted on the instrument measures the amount of time taken for each light pulse to bounce back.

Because light moves at a constant and known speed, the LiDAR instrument can then calculate the distance between itself and the target with high accuracy. By rapidly repeating the process, the LiDAR instrument builds up a complex 'picture' of the terrain it is measuring.

The data can be analysed and used in diverse applications such as:

- mapping areas for building and structures in the construction industry
- generation of digital terrain maps for use in geographic information systems
- generation of digital vegetation maps for use in the forestry and land management industries.

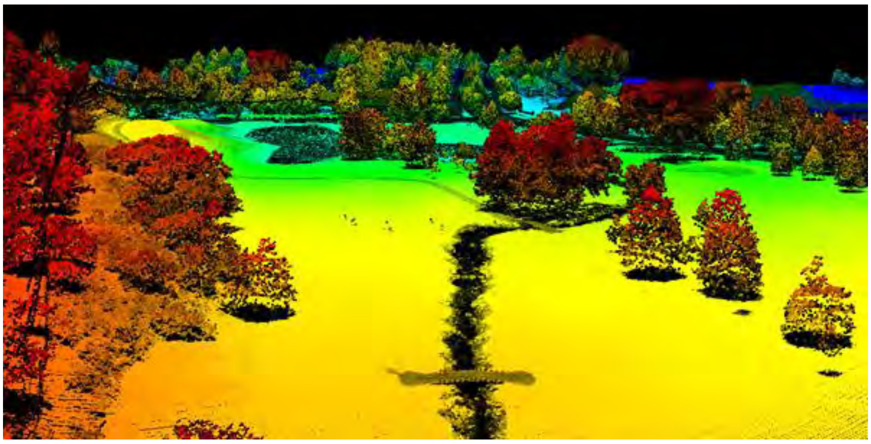
While it was originally used primarily for digital terrain mapping, more recently LiDAR is becoming increasingly useful for examining vegetation in native and plantation forests.

Treemetrics, a company based in Ireland, specialises in technology in forestry using LiDAR to assess timber volume and timber straightness within commercial plantations.

Appendix 1.0 refers to a case study on the comparisons between precision agriculture and precision forestry and the application of precision forestry for rural land management.

Airborne LiDAR has advantages over other airborne remote sensing, as it generates three-dimensional structural data because the laser pulses can penetrate the forest canopy to reach the ground.

Topcon and Trimble have vehicle-mounted terrestrial LiDAR systems that can integrate GPS location, imaging and LiDAR scanning data to produce 3D imagery of cities, towns, buildings and transport routes



Airborne LiDAR imagery (*Source: Terraimaging 2014)*

Dr Alexandre Escola of the University of Llieda, Spain, demonstrated at the European Conference on Precision Farming field day how LiDAR could be used on a self-propelled platform to measure canopy density in grape vines. LIDAR created a 3D digital representation of the vine. This information was then used for variable rate pesticide applications to apply pesticide to the crop directly as opposed to a blanket pesticide application. The **pictures below** show the pesticide applicator spraying using the lower nozzle only as there is no vine for the two higher nozzles to spray. Within the EU. orchards account for 4.4% of cropped area and account for 14 per cent of all pesticide use.

Left: LIDAR imagery displayed on a laptop

A LIDAR Data Collection Platform

Variable rate pesticide application arried out using processed LIDAR data

5.11 Radio-frequency identification (RFID)

RFID is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data. Tags have been used in agriculture for a number of years in the form of EID tagging of livestock.

The tags contain electronically stored information. Some tags are powered by and read at short ranges (a few meters) via magnetic fields (electromagnetic induction). Others use a local power source such as a battery, or else have no battery but collect energy from the interrogating EM field, and then act as a passive transponder to emit microwaves or UHF radio waves (i.e. electromagnetic radiation at high frequencies).

Battery powered tags may operate at hundreds of meters. Unlike a barcode, the tag does not necessarily need to be within line of sight of the reader, and may be embedded in the tracked object.

During my travels round Australia I stayed at Goondiwindi in Southern Queensland, a cotton growing region, and discovered that cotton harvesters use RFID for tracking and delivery of cotton bales. The bale wrap used for the cotton contains RFID tags. At the local John Deere dealership I was shown how the latest John Deere harvester system documents information that is essential to the processing of the cotton at the cotton gin (cotton processing site) - such as client, farm, field, module serial number, harvest date and time - all into one easy-to-read document. The data is then matched to the RFID tag and can be easily pulled off the in-cab display via data card or USB drive and sent electronically to the cotton gin; this then provides full product traceability.

See photo of cotton harvester on next page

Cotton harvester - Australia

5.12 Micro electronic and mechanical (MEMS) technology

When I visited the Barbara Hardy institute at the University of South Australia, Chris Saunders explained how they were working on a research project with GRDC (Grains Research and Development Corporation) funding. They were looking at the use of sensor technology designed at the University of Western Australia to provide real time optical sensing in soils and plants to potentially replace wet chemistry.

MEMS sensors are robust and stable platforms for optical sensing. Their small size and relatively simple design make them cheap and they provide a quick and simple way of collecting data and will hopefully provide data on soil moisture and nutrients in real time in the field.

5.13 Soil moisture sensors

At Agritechnica 2013 in Germany, John Deere launched their soil moisture system into the European markets. This system integrates data on soil moisture levels, temperature, rainfall and solar radiation which can be transferred by John Deere's telemetry or radio systems to the farm office where it allows wilting and saturation points to be plotted on irrigation software in real time.

Soil moisture sensors are primarily used to calculate soil water deficits for irrigation scheduling to ensure that the crop is not constrained by too much or too little water, optimising timing and duration of irrigations to improve efficiency productivity and profitability of the crop.

Increasingly they can also be used to determine available soil water plus crop water use prior to crop nutrient applications, to time nutrient applications when uptake and benefit to the crop is at its peak; thus improving efficiency, productivity and profitability whilst also being sustainable by reducing nutrient leching.

Siting of the probes is important and this can be at field level or within field soil zones identified by soil mapping and elevation, and used for variable rate irrigation.

John Deere soil moisture probe

5.14 Wireless sensor networks

In-field sensors can provide data on a range of soil and environment properties including soil temperature, soil moisture, soil acidity, temperature, humidity, barometric pressure and even information on plant growth.

Wireless sensor networks (WSN) can provide processed real time field data from sensors, distributed in the field via radio waves. The individual sensors deployed on the field measure various atmospheric and soil parameters, which can help in making decisions on the holding: for example operator-controlled or variable rate irrigation, fertiliser and pesticide applications, pest detection, yield prediction, and plant disease risk assessment.

As the sensors can emit data continually, the quantity of data can become burdensome. It is therefore recommended that data is collected and recorded at the lowest frequency appropriate to its application; this will reduce the power consumption demands for data transmission. For very slow growing crops less frequent data recording will be possible.

The data from the sensors can be collated to monitor crop development and assess ways in which potential crop yields can be improved. Sensors can also be used for monitoring the natural environment including water quality.

Smart wireless sensor networks are a technology for remotely and continuously collecting data from a large number of sensors over wide areas and therefore are suitable for monitoring and controlling crop performance and the natural environment. They are particularly useful for agriculture where site surveys can be labour intensive and expensive. If the information is supplied to a portal on the internet the data can be accessed remotely at any time and controlled.

Wireless sensor network

Transporting and collection of the low level data from farms will be no easy task. The data has to be relayed to a local base station to then be transmitted by GPRS to the farm office server where it is loaded onto the internet for remote access. The limitations of the system are that GPRS (mobile telephone data communication services) can be expensive.

Within the UK there is a new wireless network known as Weightless which is in fact utilising the redundant radio wavebands from analogue television. These wavebands are capable of carrying low data volumes - such as that produced by field sensors from base stations - to a machine very quickly. Weightless is a machine-to-machine, low-cost, low-power communication system. Due to its capabilities and low operating cost I can foresee this wireless network providing a useful service for agriculture and land management.

5.15 Smart phones ….. the new Swiss army knife

Your smart phone already knows where it is, how you are holding it, what you are saying to it and how fast you are moving - all with the aid of in-built sensors. Sensor development and incorporation into everyday items such as smart phones will undoubtedly become essential in agriculture and land management systems.

Samsung and Apple are very active in the development of sensors in smart phones and the latest Galaxy S4 incorporates infrared sensors to detect movement; light sensors measuring red, green blue and white intensity of a light source; temperature and humidity sensors; and a barometer for measuring atmospheric pressure, all of which enable you to sense the environment around you. Incorporate this, plus optical sensing technologies described earlier, inside a smart phone and, with the development of 'apps' for agriculture, they become an important management tool capable of providing ''on the go'' information on crop health and the environment. All of this can be used to plan management to maximise yield potential.

Smart phones will become the new Swiss army knife on the farm as a multifunctional tool.

6.0 Managing variability

To manage variability there are three fundamental attributes

1. Location Information (spatial referencing)
2. Measurement and monitoring of the crop, soil and environmental
3. Ability to map the variation identified

The use of the geo-referenced data collected using the technologies discussed earlier can be used for informed decision making and will often result in variable rate applications. It is important to remember that most machinery on farm at present is not capable of managing variability down to cm accuracy and that you should measure variability based on the variability you are capable of managing; but this is not to say that you should not collect data at cm accuracy as this can provide important records for the future.

Ways in which variability can be managed are set out below.

Variable rate nutrient applications:

6.1 Nitrogen

Crop sensors such as the YARA N Sensor and remote sensed imagery are used to determine crop nitrogen requirements and to map nitrogen requirements to enable variable rate nitrogen application either 'on the go' or following adjusted recommendations. Liquid nitrogen applications can be varied through spraying and prilled nitrogen applications can be varied through a fertiliser spreader. Electric drive fertiliser spreaders are providing the technology to improve the ability to manage variability more effectively.

6.2 P & K

Yield maps can be used to assess required P & K replacement which can be converted into variable rate P & K application maps.

6.3 Lime/pH

Lime can be applied at a variable rate based on geo-referenced soil mapping which provides mapped zones for variable rate lime applications.

6.4 Manure

If the nutrient value of organic manure is known, again this can be applied on a variable rate basis, as required and determined by geo referenced soil nutrient analysis.

6.5 Variable rate growth regulators

Growth regulator can be applied at varied rates depending on the amount of biomass within a particular part of a field. The more biomass the more growth regulator will be applied to that part of the field and vice versa, leading to a much more cost effective and environmentally sustainable application of growth regulator.

6.6 Variable rate seeding

Soil maps prepared using the soil electro conductivity mapping and ground truthing described earlier in the report can be used to vary seed rates according to soil type within a field. Higher seed rates may be applied to areas of a field with high clay content that may have high plant losses, and lower seed rates to more fertile land where establishment rates are expected to be higher. A variable seed rate application map is prepared and used by a drill capable of variable seed rate applications.

In the US Kinze Manufacturing have developed a multi hybrid drill capable of working with two seed varieties/ hybrids within one field chosen to match the 'in field' variability and maximise production. Trials carried out by Kinze using this concept have all demonstrated an increase in yield, which has huge potential for managing 'in field' variability. Again the functionality of the machine has been made possible by the use of more responsive and controllable electric drive rather than traditional PTO drive.

Hybrid drilled field (Source: Kinze Manufacturing 2014)

6.7 Variable rate and depth cultivations

Soil maps prepared using the soil electro conductivity mapping in conjunction with soil compaction mapping can be used for variable rate cultivations to save fuel costs in cultivating operations. In the UK Soyl is working with cultivation machinery manufacturer Cultivating Solutions to adjust the working depth of soil, loosening legs on a cultivator according to pre-defined compaction and weed maps. This improves operation speed and fuel efficiency, and can be used to control weeds such as blackgrass.

See photo on next page.

6.8 Variable rate and selective spraying

The ability to control sections on a sprayer and, in certain cases, individual nozzles, is being used for target application for the treatment of crop disease and pests. For example project URSULA uses an unmanned aerial vehicle (UAV) to identify patches of blackgrass which can then be targeted through selective spraying based on the geo-referenced data collected by URSULA rather than blanket application of the whole crop.

Variable depth cultivating machine by Cultivating Solutions

When I visited the University of Wageningen, Dr Corné Kempenaar and Frits Van Evert showed me some research they had carried out into the variable rate application of herbicide rates for potato haulm killing. They used satellite based sensor measurements to inform them of crop biomass, to then vary the rate of herbicide application for haulm killing across the potato crop. They found that when managing the crop in areas under 30m x 30m, herbicide use for haulm killing could be reduced by 50% with variable rate application.

6.9 Variable rate irrigation

During my trip to New Zealand I stayed with Nuffield Farming Scholar Craige Mackenzie and his wife in Methven. New Zealand has the benefit of excellent soils and an abundance of natural water which is well managed as a national infrastructure for crop irrigation. Craige farms 525 ha in two blocks; 225 ha of lighter land had been converted to dairying in 2008. Cropped land is used to grow feed wheat, ryegrass for seed, fescue for seed, chicory, faber beans, pak choi, onions and hemp. Irrigation is required to fill in periods of low rainfall such as November/December. Alongside the farm Craige operates a precision agriculture business and research company, Agri Optics. Craige utilises and advises on variable rate irrigation. On his holding he used both pivot and lateral irrigation systems capable of variable rate irrigation using individual nozzle control with time pulsing.

On the holding the fields had been subject to an electromagnetic soil survey and ground truthed to identify soil zones. Soil moisture in each of the soil zones was monitored with soil sensors which fed back data to Craige's office. The mapping also enables any zones that do not want to be irrigated to be identified; such as tracks, yards and water troughs.

Monitoring of soil moisture levels means that optimal soil moisture levels can be maintained. Irrigation water is applied to match the water holding capacity of each specific zone and match the use of the crops that are being grown in the individual zones.

When soil moisture levels are maintained at a level between the crop stress point and the soil full point it allows the farmer to capture every rainfall event throughout the growing season. If the farmer can do this without soils reaching the full point they will eliminate any possible drainage requirement. No drainage is the aim, as this is when soil nutrients are lost through leaching. Soil nutrients need to be maintained within the root zone to optimise nutrient uptake. Aerobic conditions – not anaerobic conditions - were key for growing high yielding crops.

Multiple layers of data can be used to model the impact of slope, aspect and drainage; to manage irrigation and limit the runoff of nutrients into waterways. The natural water of New Zealand is a valuable asset and effective management to limit nutrient loss on the farm has had a large role to play in the lack of regulation of water quality to date.

Variable rate irrigation reduces pump costs for new Zealand farmers pumping the water; improves crop yields, soil health, reduces nutrient leaching and provides estimated annual irrigation water savings of between 25 -50% on farms throughout New Zealand.

Craige Mackenzie explaining the settings on his Irrigator.

Linear Irrigator

At the University of South Queensland National Centre for Engineering in Agriculture, Dr Alison McCarthy talked me through one of her current projects: developing a low cost camera-based method to estimate irrigation and fertiliser requirements of a cotton crop. This involved the location of cameras on the pivot irrigation system. They were used to look at soil and plants for water stress to develop a real time adaptive irrigation system, which effectively automated the irrigation process. The benefits of the camera-based system are that it reduces the need for 'in field' sensors which can be expensive and which farmers must avoid with machinery when carrying out in-field operations. The sensor vision in the cameras will also be used to assess crop height, density and potential yield by looking at flowering. Dr McCarthy's research and 'in-field' trails demonstrated yield improvements of between 10-11% and water savings of 5-12 % using the variable rate automated irrigation system.

Variable rate automated irrigation system.

6.10 Selective harvesting

Where it can be justified for higher value crops, more geo-referenced data on crop quality and quantity will enable more selective harvesting to take place. When I attended the European

Conference on Precision Agriculture in Spain, Agro Pixel and New Holland demonstrated the use of remote sensing imagery to identify variability of grape maturity within a vineyard. The data from that was collected, ground truthed and analysed; then sent to the harvesting machine to selectively harvest areas of the vineyard deemed to be mature for harvest. Sub optimal maturity of grapes can have costly implications for wine quality and has been the key driver to the development of this technology.

At the University of Wageningen, Jochen Hemming showed me a robotics project he had been working on for selective harvesting of red peppers in a commercial greenhouse. The system used optical imagery to identify the red peppers, then machine robotics were used for careful selective harvesting of the individual mature peppers. *Other sensing techniques were used for a project involving the selective harvesting of cucumbers. See photos on this and following page*.

When I visited Topcon Headquarters in Adelaide I saw how they were working on developments in machine control for multi-functional variable rate technology, which means the ability to control multiple variables ‘‘on the go’’ at any one time.

This technology has the ability to meet sustainable intensification objectives by combining multiple operations, each of which addresses in field variability, in one vehicle pass, whilst minimising the impact of ‘in field’ operations on the natural environment.

Selective harvesting within a vineyard - Spain

Identifying zones for selective harvesting within a vineyard

New Holland harvester capable of selective harvesting

Topcon Headquarters - Adelaide

7.0 Robotics

Robotics in agriculture provides an automated platform for remote sensing to monitor crop health, as well as a device for carrying out variable rate applications or selective harvesting. BoniRob for example is a robot designed by Amazone capable of carrying out individual plant tasks. It can monitor through optical sensing individual plant growth status and selectively apply fertilisers plus eliminate any competing weeds. There appears to be a lot of potential for small scale robotics amongst high value crops such as salad crops. However robotics in UK arable production seems a long way from adoption as it requires a complete change in farm machinery infrastructure. On the other hand, driverless tractors are urgently awaited in Western Australia due to a lack of available labour and vast open areas of agricultural land.

Bonirob Amazone field robot

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8.0 Telematics

Telematics is the technology that has the ability to wirelessly connect to mobile devices or machines from a computer or even smartphone. It allows users to remotely collect information, send data, or control devices. In agriculture it enables computers and smart phones to connect to the computer to collect data remotely from the machine; such as fuel consumption, location, and vehicle status or, for example, whether a combine is harvesting or idle.

Telematics offers wireless data transfer, remote diagnostics, equipment tracking and maintenance scheduling, and remote dealer support. Real-time data transfer allows data to be automatically collected from equipment during field operation and uploaded to an internet server. By transferring data wirelessly, managers can edit and upload A/B lines, prescription maps, send directions to the machine operator, detect machine problems or servicing requirements.

Telematics can send alerts via text messaging or email; when a vehicle is active outside an assigned boundary (geo-fencing); error codes or warnings pertaining to machine issues; or when vehicle maintenance is required.

Machine information can be viewed in real time at the office, and machinery dealers can have access to the telematics system to obtain machine information and run diagnostics before arriving at the field, plus obtain location information about the machine to provide automatic directions to service technicians.

Telematics not only provides everyday machinery information but the data can also be used to improve the efficiency of operations. For example Birds Eye peas are currently developing a telematics system to maintain a constant flow of freshly harvested peas into the pea factories.

In order to keep the pea factories running efficiently telematics are being used to identify the location and harvest quantities from pea viners in operation, which can then be used to calculate anticipated factory deliveries. Normally problems arise when two groups of pea viners move fields at the same time resulting firstly in a reduction in factory input, and then a potential excess when the two pea viner groups get harvesting again in the next field.

Birds Eye have a time limit of 2½ hours from harvest to frozen state and maintaining 'field fresh' peas is important to them and their customers. They do not want lorries of peas queued at the factory waiting to unload. It is essential that they maintain an efficient and constant flow of peas into the factory.

Telematics enables data on the location of the pea viner, plus yield from a field, to be used for planning ahead with anticipated factory throughput. This controls the rate of harvesting of individual pea viner groups and maximises the efficiency of the harvesting, washing and freezing process.

Birds Eye are also utilising an in-house GIS system to record the location of pea crops each year, plus historic information on pests, diseases and waterlogging; all of which can be recorded and used to carry out a financial appraisal as to whether to take the field another year when it next becomes available in the rotation. As, in order to attract supply, Birds Eye pea growers are paid on a fixed rate per acre even where there is a loss, this information becomes essential for Birds Eye to manage quality and sustainability.

Birds Eye pea viner In operation in the field in 2014

9.0 Remote livestock management

Elements of precision livestock farming impact upon how land is managed. From my visits to the University of New England, New South Wales, Australia and the Precision Agriculture Research Group I saw how technology in remote tracking of livestock movements could be used to monitor livestock grazing and soil erosion.

Zac Economou, a researcher, used livestock collars with ear tags attached to track animal location. The ear tag sends out a radio signal that is picked up by the wireless network, which triangulates the signal and sends the time, location and individual identity of each animal to the server. This could be uploaded into a geographical information system to map livestock movements. Zac used this information, together with information about soil type, pasture quality and livestock grazing, to identify areas of a paddock susceptible to soil erosion and damage by livestock. He explained how this data could be used combined with geo/virtual fencing to protect against soil erosion at times of high risk.

Zac was also carrying out research into geo-fencing, using the same location technology. Geo-fencing utilises mapped virtual fence lines and when these virtual fences are approached by livestock they would hear a warning tone emitted from the collar they were wearing. If they continued over the virtual fence line they would obtain a mild electric shock from the collar. Virtual fencing systems provide a range of remote solutions to livestock farmers who can provide additional grazing from a computer screen thus improving pasture utilisation, nutrient distribution and reducing soil erosion.

See photo of cattle tracking collar on next page.

Sensors can also be used to monitor livestock health and movements, for example a thermometer attached to an ear tag can be used to monitor animal health remotely and this can be combined with other information such as livestock movement data.

The real advances in livestock management will come when data on animal behaviour and production is combined to provide a practical management tool. An example of this would be the ability to determine how much grass to give cattle, based on their activity and potential production on a 3 hourly basis, remotely with geo/virtual fencing.

In December 2013 I attended a Conference at Harper Adams University titled ‘Unmanned aerial systems in Precision Agriculture’. At the event Marc-Alexandre Favier presented on the use of UAV systems in precision livestock farming. He showed how UAV systems could be used to monitor livestock in remote areas, map livestock location using image shape recognition, muster livestock, separate sick animals and even treat animals remotely.

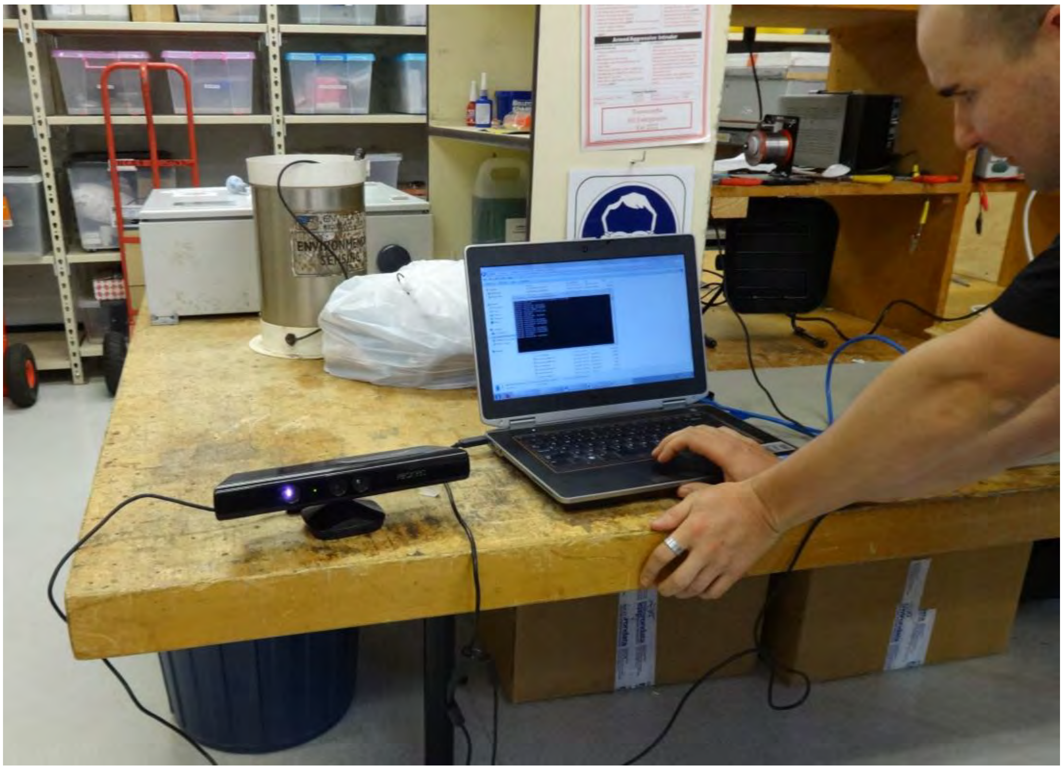
At South Queensland University Dr Matthew Tscharke had used a Kinect sensor from an X box games console to predict pig weights in a pig fattening system. The Kinect sensor, a low priced LiDAR type sensor which measures depth and is capable of producing a 3D image, was mounted above pig feeders and identified pigs from their RFID tags, then create a 3D image of the pig. This was then used to determine weight and was calibrated to provide an accurate remote weighing device for pigs.

This type of system enables greater control over live weight gain management and reduces handling requirements and therefore stress amongst the animals.

Cattle tracking collar

To balance productivity and pasture degradation, managers in livestock systems have to make assessments about stocking rate and length of grazing. Research at the University of New England compared the spatial area of livestock grazing estimated by the farm manager - assessed on factors such as the location of water troughs and shade - against the actual area of spatial spread of grazing in a paddock, using tracking collars. They found that the manager predicted that only 44% of the paddock area would be grazed, but in fact 70% was being grazed. This demonstrates that research into the factors affecting spatial distribution of grazing can provide decision making tools for more efficient and environmentally sustainable pasture management.

During my time at the University of New England I was taken to Sundown Pastoral Farms north of Armidale, Australia, where they were integrating remote livestock management and remote sensing techniques on the holding in order to pursue sustainable intensification. My case study of Sundown Pastoral Company is attached in **Appendix 2.0**



Kinect X box games console sensor used for 3D imagery and weight assessment of livestock

10.0 Managing data

Based on the technologies discussed, agriculture is capable of producing a vast amount of data, all of which needs to be managed and interpreted effectively. In order to do this a geographical information system (GIS) is required at a farm level. This would be referred to as a farm management information system or Farm GIS system.

From my travels I found that data collection within precision agriculture is not a problem - but data management is. Data only becomes useful when it is organised, analysed and converted into a management practice and it is these elements that require time, money, good computer skills and patience.

10.1 Geographical information systems

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS can show a broad spectrum of geo-referenced data on one map and enables people to visualise, analyse, and understand patterns and relationships between data sets such as the effect of soil type on yield.

There are a wide variety of GIS/Farm GIS systems on the market ranging from large commercial GIS systems capable of vast data sets - such as Esri Arc GIS - to farm focused GIS systems such as Farmworks and Gatekeeper in the UK. The larger commercial systems are very expensive whereas the smaller farm based systems are more affordable.

For many farmers maintaining their own farm GIS system is a large time and administrative burden and they may look to a data manager to organise and analyse the data. This may be an independent data consultant who then provides raw data for agronomists to convert into management data, or it may be an independent agronomist capable of managing and interpreting the data.

In South Australia I visited Michael Wells who became involved in precision agriculture following a career in the fertiliser industry. Michael operates a solution-based agricultural GIS system and acts as a data processing lab to process farmers' data on his own software. The software has been designed to eliminate complexity and turn data into information, turning questions into answers with profitable results, and I believe that this should be the driver behind all precision agriculture data management software.

Farmers were uploading their collected data onto Michael's system which he could then organise, edit and clean.

The basic information being uploaded onto the system included soil mapping information from soil surveys using EM38 surveys and Gamma radio metrics, topography from farm in-cab GPS, and yield data together with imagery from crop sensors or satellite imagery. Michael would work with farmers and the agronomists to obtain a background to the holding and identify the causes of variability and appraise existing farming systems.

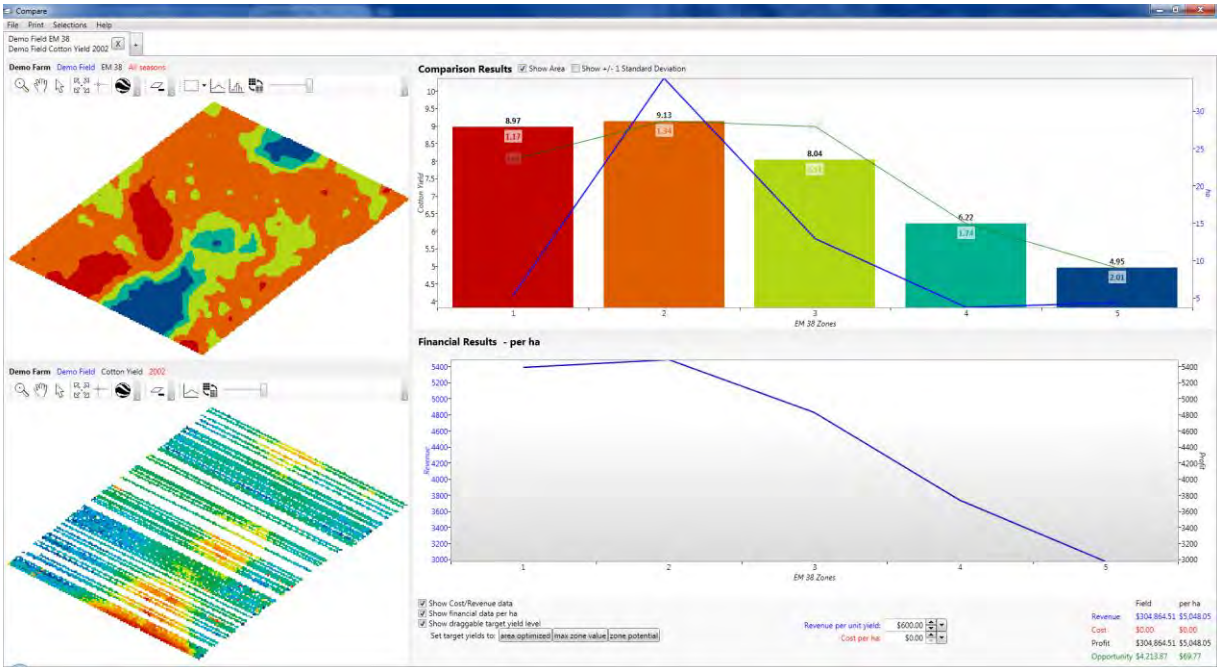
Within the software system was functionality to overlay maps. For example, we looked at overlaying yield maps onto EM38 soil survey maps. The system also enables you to compare using inbuilt statistical analysis so you could plot a comparison of yield and soil survey results to assess the correlation. The data can then be used to create prescription rate maps for variable rate applications. Cost analysis could be carried out to assess how to maximise the benefit of an input in terms of price and costs.

The software also assisted in the location of soil probes, based on soil type and topography data already collected on the system, to provide representative soil probe location.

Farm trials could also be easily established, managed and analysed using the software, which would also run a report and cost benefit analysis.

As an 'add on', the system also had a grade design system which generated digital elevation models to simulate surface water flow; from which land drainage systems could be designed, modelled and costed.

The whole system could be viewed by farmers and their agronomists; Michael was carrying out data interpretation and prescription mapping for agronomists, which were varied according to an individual agronomist's advice.



The screenshot above shows cotton yield overlaid onto soil zones derived from an EM survey. The graph shows that as EM increases the yield goes down. The blue line on the top graph shows that actual returns from that crop, but the green line shows potential returns based on managing the variability efficiently.

Michael pointed out that the more information you have the better informed you are, and that 'effective' agronomists are required to work with variable rate and on farm trials.

10.2 Data collection

Data can be collected in a number of file formats and only certain GIS systems will use certain file formats. This can make transfer of data and use of data between different advisors, machinery, and software systems difficult. Whilst a lot has been done to standardise data for use on multiple platforms it can be an issue that causes delays in interpretation and utilisation of data.

10.3 ISOBUS – ISO 11783

ISOBUS is based on the international ISO 11783 standard 'Tractors and machinery for agriculture and forestry – Serial control and communications data' network. International agricultural equipment manufacturers have agreed on ISOBUS as a universal protocol for communication between implements, tractors and computers. The Agricultural Industry Electronics Foundation (AEF) oversees ISOBUS and aims to standardise communication between tractors and implements whilst ensuring compatibility of data transfer between the mobile systems and the office software used on the farm.

'AEF Project group 9: Farm Management Information Systems (FMIS)' is the ninth ISOBUS project group of the AEF. The main areas of work for this group are the harmonisation and expansion of existing standards for interfaces for data transfer, and the development of implementation recommendations (AEF guidelines) for manufacturers of machine electronics and management software to improve inter-manufacturer machine compatitibility.

10.4 Data ownership - who owns the data?

The ownership of precision farming data has been the subject of much discussion. Primarily the data should be owned by the farmer and the owner of land from which the data has arisen to maintain continuity of records. The farmer or land owner can then make decisions as to whom he shares his data with; for example he may share the data with his agronomist for advice or share it with his fertiliser supplier to order fertiliser based on the crop requirement.

If data is limited to the ownership of the farmer it is not to say that opportunities should not be available for farmers' data to be used for advancement in the form of benchmarking or research, and ways of sharing the data for such uses needs to be carefully considered as well as being optional.

Machinery telematics systems are already collecting vast amounts of data from machines 'on farm'. The data collected will have a value for marketing and research purposes so care needs to be taken that data is not automatically being used by machinery companies or other companies providing precision agriculture services, and being sold on to other companies with no financial consideration to the farmer. Project URSULA collects farm data for a fee but then retains ownership of the data, only licensing the use of the data to the farmer or his advisors.

Farmers' and landowners' data should be protected allowing them to determine who has access to the data. A UK protocol is required as to ownership of data harvested from the land.

10.5 Cloud Data

Using the cloud as a way of storing data enables the data to be accessed securely from any location by designated people such as advisors.

Immediate availability of data between all those connected with a farm enables faster decisions to be made between people in different locations plus immediate update of records once an action has been carried out. The data is automatically backed up on the cloud and difficult to lose.

One example of a cloud based system is 365.Farmnet. This was launched at Agritechnica 2013 and is a cloud based farm management information platform into which farmers subscribe to upload their data, and can then buy into other applications of partner companies. For example if a farmer signs up to use the KWS application, KWS will use the uploaded information on soil type and proposed cropping to suggest three seed varieties. The system also incorporates an ordering and delivery system based on the geo-referenced information held on the 365.Farmnet system.

The benefits of this type of system are that it is a platform from which multiple suppliers and advisors can provide their services and farmers can buy into, using their information already loaded onto the system. 365 Farmnet is not available in the UK as yet but is anticipated in the near future.

365FarmNet

Partner	Service
GSA	**European GNSS Agency (GSA) - Satellite technology** Provision and utilisation of EGNOS and GALILEO for agricultural management.
Allianz	**Allianz -Measurement of biomass for Agricultural insurance** The Allianz application uses biomass data collected from Satellite imagery for crop management and crop insurance and assessing the validity and extent of loss claims.
CLAAS	**CLAAS- Integration of telemetry data.** The Claas application links the telematics data from the machine with 365FarmNet. So service scheduling data, yield mapping, machine location and geo fencing can all be easily visualised on one portal. The system also allows for automatic posting of machine setting proposals based on machine data.

	KWS SAAT AG -Corn adviser Data loaded onto the customer 365 farm net platform is used for seed variety recommendations, ordering and delivery.
	Bayer - Agro weather, diagnosis, plant protection consultancy. The Bayer application provides information about weather forecasting supplying precise, small-scale high-resolution weather information and forecasts directly for the farm location. The diagnostics function determines pests, broad-leaved weeds and grass weeds as well as diseases and presents appropriate product solutions. The plant protection adviser makes specific application recommendations in spring and autumn.
	AMAZONEN-Werke - Machine settings of fertiliser spreaders 365FarmNet links information from fertiliser planning with master data of the Amazone machine on the farm. 365FarmNet determines automatically the correct machine settings for the Amazone fertiliser spreader.

10.6 Summary

It is clear that the data has a lot to tell us but we do not know the full extent of what; development of agricultural systems will become increasingly dependent on the ability to access and exploit information.

The UK Strategy for Agricultural Technologies published in July 2013 set out the government's proposal to establish a Centre for Agricultural Informatics and Metrics of Sustainability. This centre is intended to develop and promote best practice in data analysis for the wider benefit of the agri-tech sector. It will aid understanding of physical, biological, economic, social and environmental factors and the way they interact to affect agricultural systems, plus the supply chains that flow into and from primary production.

From the substantial volumes of data being generated by researchers, farming businesses, distributors, retailers, consumers and others involved in agriculture and food supply chains there are many opportunities to add value. Integrating large, diverse data sets with information from other sources - such as from socio-economic, satellite imaging, environmental monitoring, meteorology and soil geochemistry data, known as geo-intelligence - will drive innovation and improve sustainability throughout UK agriculture.

11. Modelling and simulation

During my travels it became apparent to me that as data becomes more available for every aspect of life, modelling and simulation provides the key for interpretation and practical application of the large volumes of data.

At the University of South Australia I was shown how modelling was used for 3D tillage simulation, to simulate the effectiveness of cultivation machinery. The potential reaction of each soil particle to a cultivation operation was modelled to simulate the outcome of the cultivation operation which could then be assessed against other operations.

Simulation has an important role to play in the analysis and utilisation of the agricultural data. Data can be modelled, based on data obtained during a growing season, to provide projected yield outcomes.

Data can be combined and analysed empirically on the basis of outcomes of past experimental data, or be analysed mechanically to represent the processes that are involved in crop growth. Mechanical analysis can account for a larger number of variables such as weather and soil condition, and be capable of analysing different 'what if' scenarios.

In Australia there are two subscription-based crop simulation models available for growers and advisors to address the issue of yield potential: the Agricultural Production Systems Simulator (APSIM) and Yield Prophet. APSIM is a complex system but available in a more user friendly web based system referred to as Yield Prophet.

Yield Prophet is used to assist management decisions through a season. Growers or their advisors enter their inputs during a season and the system reports on projected yield showing the impact of sowing time, nitrogen management and irrigation on crop yield.

Yield Prophet allows growers or their advisors to carry out:

- Assessment of sowing date and variety for greatest yield potential, including frost and heat-shock risk
- Real time assessment of crop yield potential through the growing season
- Benchmarking of crop growth and performance, resource use and availability (water and nitrogen)
- Impact of different nitrogen fertiliser rates and strategies on yield forecasts
- Probability of a positive gross margin on nitrogen fertiliser inputs
- Relative comparison of hay and grain yield
- Impact of climate change on paddock-level production

I have not come across anything similar (to this Australian system)in the UK but the development of such cropping simulators to utilise the vast amounts of geo referenced data that will be

produced by precision agriculture will be essential in assessing the yield potential of land and potential return against inputs plus environmental impact.

The use of modelling for proposed drainage schemes using digital elevation data and water flow information enables a drainage scheme to be costed and assessed against benefit. Modelling will become important for infrastructural investments on farms.

Whilst modelling and simulation will provide management decision support systems, care must be taken to ensure that these systems are not relied upon and an individual's knowledge and skill is not lost.

Whilst staying with Peter Kaylock a 2013 Australian Nuffield Scholar I met Ian Delmenico, an agronomist, He was using a simple modelling system to assess yield potential on Peter's farm. Further information is attached in **Appendix 3.0 as** a case study.

12. Integration of technologies – smart farms

Smart farms utilise a range of precision agriculture technologies. At the University of New England in Armidale, New South Wales, Australia, they are working on a collaborative venture with the Commonwealth Scientific Industrial Research Organisation (CSIRO) - with the support of the Australian centre for broadband innovation (ACBI) - to turn Kirby Farm, a commercial farm and research station owned by the university, into a 'smart farm' (sustainable, manageable and accessible rural technologies) that will demonstrate the benefits of broadband wireless connectivity for agricultural and rural communities. The project has received an AUS $36 million government grant for completion of the project.

Kirby Farm extends to 2800 ha and produces merino wool from approximately 7000 ewes, as well as grazing 100 beef cattle and producing grains for livestock feed. The smart farm provides digital services to remotely monitor soil moisture levels, livestock movements and farm security as well as the ability to communicate quickly with advisors.

The objective of the farm is to demonstrate the latest on-site technologies aimed at improving productivity, environmental sustainability, safety, and workflow plus social/business support networks on Australian farms.

At the start of the project all the assets of the farm were mapped using GPS: such as fences, water points and on-farm infrastructure. Electromagnetic induction soil surveys were carried out on the holding; digital elevation mapping, remote optical sensor pasture surveys using airborne and satellite imagery together with soil nutrient mapping were also undertaken.

12.1 Sensors

A wireless sensor network for the monitoring of soil conditions has been developed and deployed as part of the project. One hundred wireless monitoring stations each sample soil moisture, soil temperature, soil electrical conductivity, and air temperature every 5 minutes. A smaller number of other sensors, such as weather stations and light sensors, are also spread across the farm.

The soil sensor information is uploaded onto a cloud based platform which enables readings to be checked remotely for each sensor.

These sensors provide vital information that can be used to advise on irrigation, livestock grazing and when to sow crops or pastures, plus when to fertilise. This information can help farmers increase their crop and pasture yields by targeting the use of water and fertilisers and to increase stocking rates through better pasture management.

12.2 Local wireless networks

Local wireless networks across the farm allow the fixed and mobile sensors to send a continuous stream of data to a remote cloud based computing and analytical service.

The soil sensors use a wireless network to send a signal back to a central collection point for data, which is located in a farm building. From here the data can *either* be sent by the wireless broadband network *or* mobile data link back to a cloud computing service.

12.3 Livestock monitoring

Over the farm there is a private wireless network, which consists of four receiver towers located about 5 to 8km apart on the property. They house an antenna, a power pack and telemetry system. This contains a modem that receives and relays the radio signal from animal ear-tags. Geographic information system (GIS) software converts this data to spatially located information to view livestock movements across the holding.

Each ear-tag is registered against an individual animal identification. The tag sends out a radio signal that is picked up by the network, which triangulates the signal and sends the time, location and individual identity of each animal to the server.

This information is being used to monitor animal behaviour; changes in behaviour that may indicate a problem can generate warnings for farmers or farm managers such as: livestock outside their normal boundary fences: an animal that has not moved for some time, or is unsettled. Jess Roberts, whom I met at Lincoln Agritech, New Zealand, was a former student at the University of New England and her research had indicated that, once pasture cover falls below about 1500kg of dry matter per hectare, animals spend less time grazing and more time seeking pasture; consequently they start to lose condition. Warnings can therefore be sent to the farm manager notifying him that the animals need to be moved to new pastures.

Other research at UNE has demonstrated a link between worm burden and the grazing pattern of sheep.

The Armidale Smart Farm has also been using CSIRO-developed cattle tracking technology that incorporates accelerometers and GPS devices that can provide more fine-detailed information about livestock movement and behaviour.

The Smart Farm Information Platform brings many different data sources together in a user-friendly and practical way. These data sources include the on-farm sensor data from the soil and livestock nodes, as well as from off-farm data such as weather and water information. The Information Platform displays, through a web browser, an aerial map view of the property so the farmer can see each sensor and instantly access the collected information.

This information is presented in easily understandable and practical ways to give a real-time picture of everything from the farm's soil conditions to stock locations at any given time.

The system will provide a valuable decision-making support system from which a farm can be monitored remotely or used for managing vast areas of farmland such as those found in Australia.

The smart farm also incorporates the use of miniature headset cameras connected to local wireless networks to allow farmers to remotely troubleshoot machinery problems with their local mechanic, or diagnose animal health problems with their local vet. Other proposals include the installation of cameras in feeding areas to monitor factors such as livestock health, weight, ID etc.

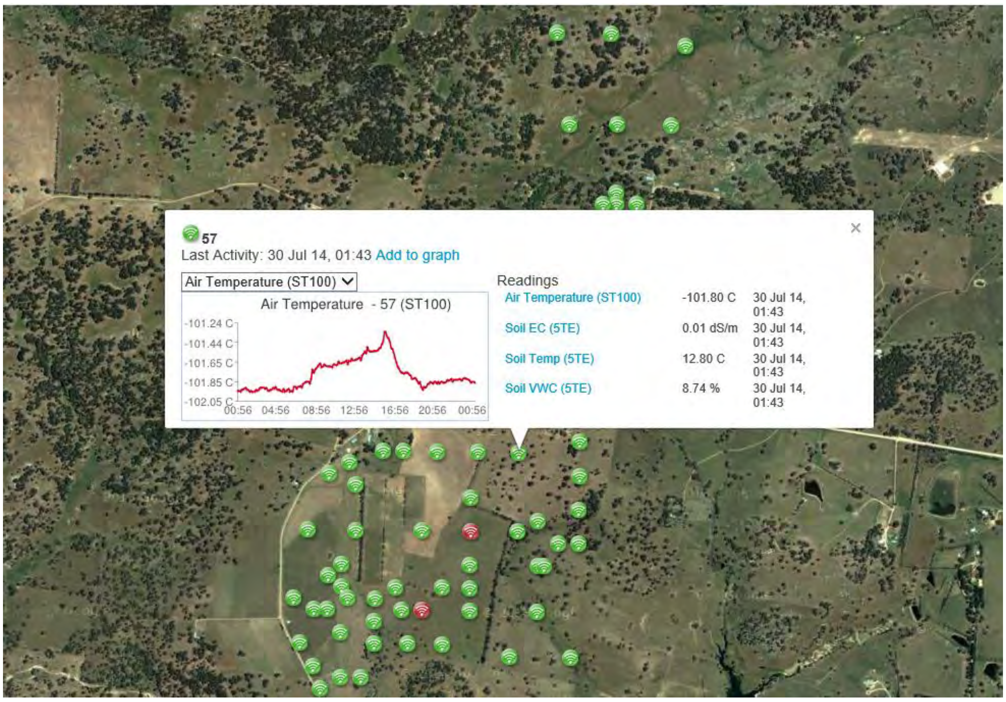
12.4 The smart farmhouse

While I was at the University of New England construction of a smart farmhouse was underway, designed to demonstrate the benefits of broadband connectivity such as video conferencing. The smart farmhouse will also be set up as a connected classroom where students of all ages and community groups can access the latest data streaming from a range of field, animal and machinery sensors, and participate in 'virtual' field days from their classroom.

12.5 Summary

The smart farm provides an excellent facility for monitoring livestock behaviour and pasture conditions remotely. It provides a base for further research into livestock behaviour and pasture management and demonstrates the possibilities for integration of technologies and the other parameters of livestock production or land management that can be investigated.

Smart farming operations will incorporate as many of the technologies relevant and available and harvest data to improve efficiency.



An extract of Kirby SMART farm sensor platform *Source: CSIRO July 2014* (http://sensornets.csiro.au/deployments/684)

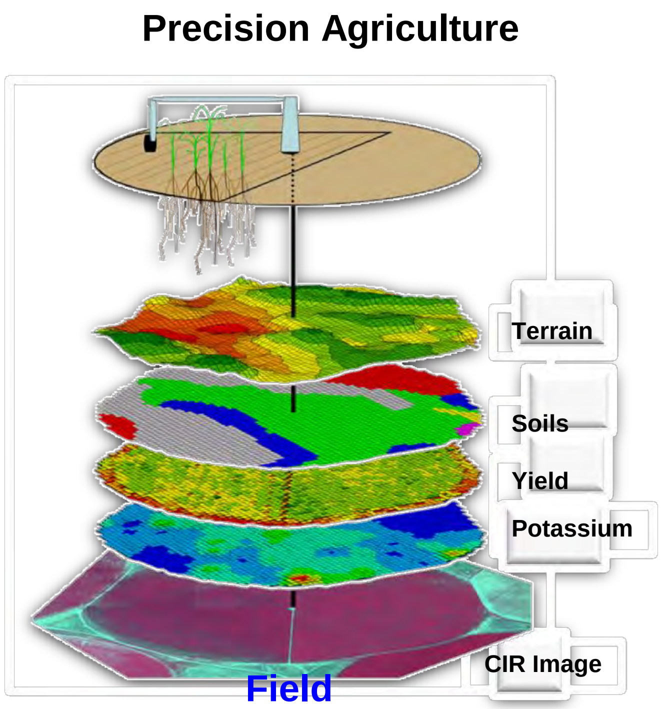
13. Precision agriculture and the environment

There is no doubt that precision agriculture has environmental benefits resulting from the application of inputs in the right place and at the right time. However in North America the concept of precision conservation has developed, targeting conservation practices with potential site-specific applications to reduce soil erosion and leaching plus contributing to soil and water conservation.

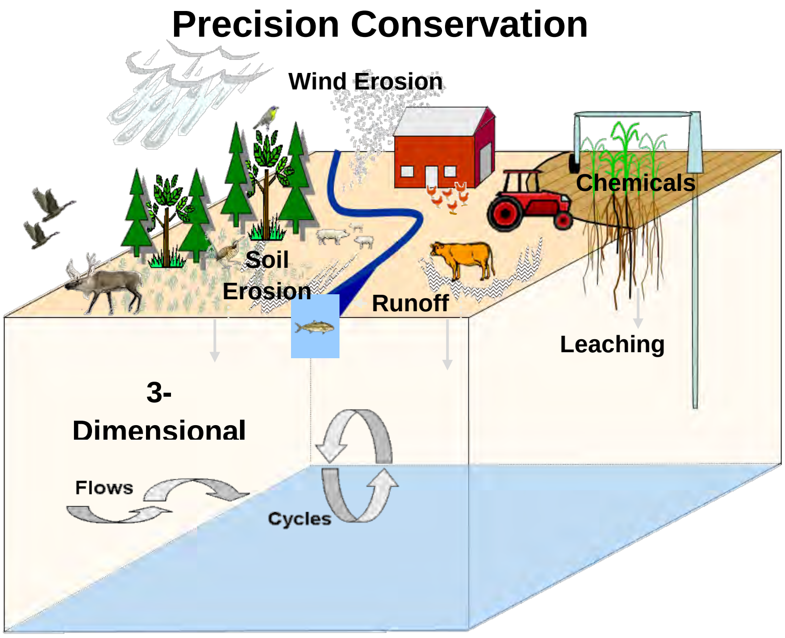
13.1 Precision conservation

Precision conservation offers the ability to integrate the use of spatial technologies such as GPS remote sensing and geographic information systems, plus the ability to analyse spatial relationships within and among mapped data, in order to develop management plans that account for the temporal and spatial variability of flows in the environment (*Delago et al 2008)*

Data collected using remote sensing, LiDAR, and GPS can provide important information on land use and elevation. Advances in modelling techniques mean that is now possible to model the potential for flooding, soil erosion and nutrient leaching. As this information can be modelled, conservation practices can be targeted based on an assessment of risk to reduce the impact of these issues on the environment: for example locating buffer strips in fields to prevent soil deposits from soil erosion from entering adjacent watercourses. Precision conservation has the potential to manage agricultural systems through conservation practices that increase sustainability.



Precision agriculture is a small but important part of precision conservation



Landscape perspective

Precision conservation connects farm fields, grasslands, and managed forests with their natural surrounding areas such as buffers, riparian zones, natural forest, and water bodies; then uses information about localised surface and subsurface flows and cycles to analyse and better understand ecosystem processes leading to the best management practices for conservation and sustainability of agricultural, rangeland, and natural areas. *Source J K Berry 2014*

Delago et al 2008 proposed that to maintain the necessary maximum production, a parallel increase in conservation practices must take place.

The use of variable rate fertiliser applications is a form of precision conservation. Using remote sensing techniques to synchronise nitrogen application with crop nitrogen demands during the growing season is also a form of precision conservation. *Delgado and Bausch 2005* identified that this could increase nitrogen use efficiency by almost 50% whilst sustaining yields and reducing leaching by 47%.

At the University of Adelaide, Professor Wayne Meyer from the Environment Institute is working on a system that utilises satellite imagery to quantify soil exposure and vegetation cover to provide an accurate measure of soil erosion risk, to enable targeting of land management practices to reduce any potential risk of soil erosion.

Practitioners and conservationists will need to work with soil scientists, agronomists, farmers and environmentalists to develop sustainable cropping systems that will maximise agricultural production whilst conserving soil and water resources. (*Delago et al 2008)*

Precision conservation can help scientists and practitioners find new techniques to maximise production whilst achieving soil and water conservation for agricultural land - such as cover crop implementation and buffer strips.

Examples of conservation practices with potential site specific applications to reduce soil erosion, leaching and contribute to soil and water conservation include:

Agro forestry	**Conservation crop rotations**
Cover Crops	**Buffer Strips**
Woodland Planting	**Filter Strips**
Crop Residue Management	**Strategic location of Supplementary feeding**
Sediment Ponds	**Set Aside**
Nutrient Traps	

The EU Water Framework Directive (WFD) was adopted in 2000. The purpose of the Directive is to establish a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters (to one nautical mile) and groundwater.

To meet the objectives of the WFD, EU Member States have established River Basin Districts and developed Plans and Programmes of Measures that detail the actions that need to be taken within each district. The overall aim is for the 'water bodies' and 'protected areas' within each river basin district to achieve 'good ecological status' by 2015.

Under the Catchment Sensitive Farming (CSF) programme £21million has been available in capital grants for farmers in specific catchments to improve and install facilities to reduce the level of diffuse pollution in rivers, groundwater and other aquatic habitats caused by farming operations. Defra statistics state:

> Agriculture contributes around 25% of the phosphate in English waters and between 25–50% of the pathogen loadings which affect England's bathing waters.
>
> Up to 75% of sediment input into rivers can be attributed to agriculture. This reduces water clarity and causes serious problems for fish, plants and insects.

The UK government has identified that we need to improve the quality of our open waters, which include rivers, streams, lakes, estuaries, coastal waters and groundwater. Only 27% of our water-bodies in England are currently classified as being of 'good status' under standards set down by the EU water framework directive.

Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015.

Precision conservation has the potential in the UK to target conservation practices to specific locations; for example areas at risk of soil erosion and nutrient leaching. This would assist in meeting the requirements of the EU Water Framework Directive but will require modelling of environmental systems to assess risk of factors such as soil erosion.

Precision Conservation could also integrate ecosystem data on species to provide ecological intelligence at a farm level to assist in the location of environmental stewardship options that provide habitats to support recognised species in need of conservation e.g. lapwing.

Unfortunately there is very little ecological data collected at a farm level unless specific studies have been carried out by Natural England or research institutes.

Targeting of subsidised conservation practices would also provide greater environmental benefit per pound of stewardship payments.

13.2 Soil management

13.2.i Controlled traffic farming (CTF)

The concept of controlled traffic farming as a way of reducing compaction and maximising the water holding capacity of the soils is relatively widespread in Australia. In continuous cropping systems up to 85% of the field can be compacted from machinery, reducing the yield potential of the land.

CTF operates to ensure that all operations carried out within a field use the same tracks, restricting compaction to specific access tracks. This is carried out with the assistance of machine guidance systems. Machinery will be set up to a standard track width which will be based on the machine with the widest non-adjustable track width which in most cases is the combine. Other machinery, e.g. tractors and trailers, have their track width set to the same measurement so that one track width can be maintained.

European traffic regulations make the adoption of CTF difficult where regular road travel is required, because extended track widths may be illegal.

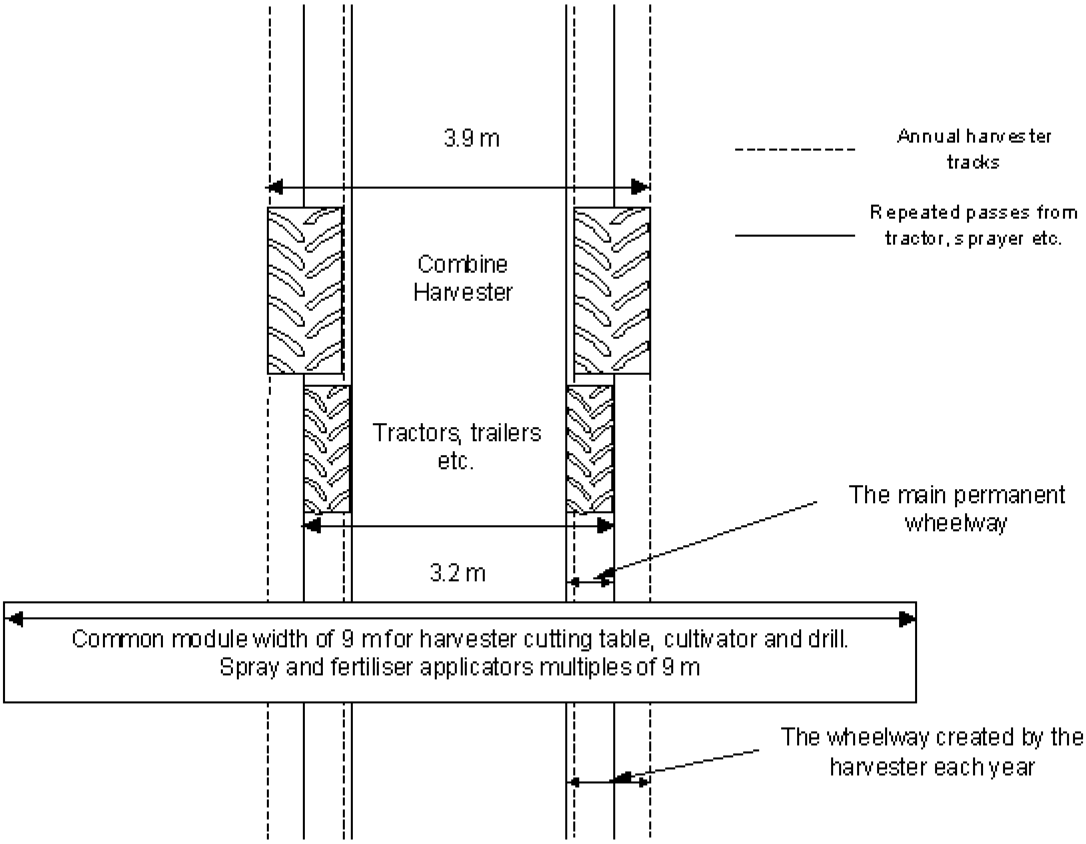
The concept of CTF has led to a lot of on-farm adaptation of track width but increasingly machinery manufacturers are providing optional extras for CTF systems such as grain auger extensions for combines.

When I was in Australia on my travels I stayed with David Cook who farms 1050ha outside Shepparton, Victoria. He was operating a 9m CTF system with 3.10m wheelings. David had planned his CTF system, based on an assessment of overland water flow, for optimal placement and orientation of the permanent tramlines to enable water to flow away from areas subject to waterlogging. David's interest was developing conservation agriculture on his holding; no till using a cross slot drill and CTF were essential to his objectives of managing the soil and conserving soil moisture.

The benefits of controlled traffic farming include:

- Reduced field compaction
- Improved water infiltration
- Improved drainage and reduced waterlogging
- Management of soil erosion risk
- Reduced fuel costs
- Reduced operator fatigue.

Wetter harvests in the UK when soil traffic is at its highest mean that soil compaction is becoming an increasing problem that needs to be identified and managed on most farms to maximise potential yield.



Source CTF Europe 2014

The author with David Cook

13.2.ii Precision conservation agriculture

The principles of conservation agriculture involve: minimising soil disturbance, using crop rotations or associations, keeping soil covered with crop residue.

Precision conservation agriculture is where conservation agriculture is applied variably across a holding to meet site specific requirements. Conservation agriculture was common practice in Australia due to the overall requirement to retain soil moisture in the ground; this was practised on a field by field basis.

Mark Branson in South Australia, a Nuffield Farming Scholar who had studied conservation agriculture, showed me how he had applied conservation agriculture and precision agriculture on his 1200 ha holding and was also using controlled traffic farming (CTF). This demonstrated to me that a combination of these technologies provided a valuable contribution to sustainable land management.

Precision conservation agriculture can be applied in the UK to protect areas prone to soil erosion or where there were shallower soils.

13.2.iii Water management

Precision agriculture, both within the UK and around the world, appears very focused on nutrient management and soil acidity as a driver for increasing productivity when soil water availability is often being limited by soil degradation.

Lal (1993, 1997) observed the processes causing soil degradation as being: loss of soil structure, compaction, crusting, erosion relating to the physical attributes of the soil, nutrient depletion, acidification, salinisation, element imbalance related to soil, depletion of soil organic matter plus alteration in the diversity and activity of soil micro organisms representing the biological component of the soils.

Soil water can be improved at a point in time by irrigation, but for sustainable agriculture it is important to manage the soil to maximise the soil water availability and holding capacity. Soil resource management affects future food security.*(Lal 2010)*

A more integrated approach is required within precision agriculture to support soil management decisions that improve soil water availability. Controlled traffic farming is the start in certain cases but careful consideration of farm layout is required..

Farm layout can be assessed based on a digital elevation model which provides information on the surface hydrology of a field and existing farm drainage. It must also consider optimising operational efficiency for the farm and identifying those areas of the holding most suitable for access and areas of the field most suitable for CTF tracks. Carefully appraising farm layout can reduce waterlogging, reduce the risk of erosion and improve trafficability of the land after heavy rainfall.

14.0 Adoption of precision agriculture

DEFRA statistics from the Farm Practices Survey 2012 showed that 43% of farmers surveyed in the UK were using some form of precision agriculture application on their farm.

22% of farmers surveyed were using GPS including auto steer and guidance in 2012. This was an increase of 8% from 2009. 20% of farmers surveyed were using soil mapping and 16% using variable rate application technologies. Only 11% were using yield mapping.

The statistics are based on the number of farms using the technologies whereas I believe a much more representational survey would look at the total area of land managed using these technologies, for in my experience the technologies are adopted on larger holdings.

14.1 Reasons for using precision agriculture

76% of farmers used precision agriculture as they felt it improved accuracy; 63% used it as they felt it reduced input costs and 48% to improve soil conditions.

Of those not using precision agriculture 47% of those surveyed said they believed it was not cost effective, or the initial set up costs were too high. 28% felt it was not suitable or appropriate for the type or size of farm and 27% felt it was too complicated to use.

Contrast this with the findings of a survey carried out in Australia by the CSIRO in October 2012. Just under 80% of farmers surveyed in Australia were using auto steer. Out of the 60% with yield monitors only 33% had yield maps and 15% of farmers were using variable rate technology (VRT). The uptake of VRT showed big differences between regions; with 37% using VRT in the Mallee region of Victoria where soils are known to be significantly variable, but only 6% in the Wimmera area of Victoria.

55% of respondents to the survey expected to adopt variable rate technologies within the next five years. The survey reflected the same opinions as did the UK survey in that some were sceptical of the new technologies because of the anticipated cost.

35% of farmers were equipped for variable rate technology but only 15% were actually using it.

The key factors found to affect the adoption of precision agriculture technologies were:

- The degree of variability of soils on a farm
- Anticipated financial gains
- Education about precision agriculture and its opportunities
- Ability to use a computer
- Availability of precision agriculture advisors and agronomists with precision agriculture knowledge.

14.2 Cost of precision agriculture

Auto steer systems have become more affordable. 2014 prices for entry level low accuracy guidance systems with an accuracy of +/- 20cm cost between £900 to £1400. Mid-range systems providing auto steer accuracy of 8-10cm cost between £8,000 and £10,000 including correction services.

To retro fit a tractor with RTK level accuracy auto steer costs in the region of £15,000-£20,000, with an RTK correction signal fee of £600 per annum or purchase of a private base station costing around £10-15,000. In reality many new tractors are auto steer-ready with the ability to upgrade to RTK accuracy with a RTK correction signal.

Due to the cost of the equipment it is clear to see why larger farms appear to adopt precision agriculture earlier; they benefit through economies of scale. Crop sensors such as the Yara N Sensor are not cheap either but, again, the larger the farm the greater the area to spread the cost.

It is for this reason that contractors operating with the use of precision farming technologies can add value to their services. As well as spreading the cost of investment in precision agriculture technologies, I believe contractors have a role to play in making precision agriculture available to a wider range of farmers, providing additional services for farm data management and variable rate applications.

From my study it is evident that the EU commission is aware of the benefits of precision agriculture for both farming, the environment and natural resource protection, and new rural development schemes will provide funding for investment in these technologies.

Technology is moving quickly as wireless-smart sensors become ubiquitous and cheap. There is an explosion of data, and we are getting a better understanding of the world around us. The range of technology now means that appropriate technologies can be selected to meet the requirements and finances of the enterprise

14.3 Discussion

In the UK and around the world we need to do more research into the agronomic interpretation of the data to provide useful management outputs for farmers.

If only 11% of farmers are using *yield* mapping against 20% using *soil* mapping are they actually addressing the issue of yield potential? It may be that yield mapping is limited by the number of combines with the technology fitted and capable of being used reliably.

At the European Conference on Precision Agriculture In Spain 2013, Jess Lowenberg- DeBoer from the University of Purdue, America, addressed the issue of adoption of precision agriculture. He identified two elements of precision agriculture: ‘information intensive’ and ‘embodied knowledge’.

Embodied knowledge referred to the element of precision agriculture requiring little additional skill - such as GPS auto guidance or ‘‘on the go’’ sensors. He considered this against the information-intensive element of precision agriculture, which requires additional data and skill to utilise; or field level data to make decisions; or the assistance of an agronomist for using technologies such as variable rate technology. He found that embodied technologies were the most readily adopted as users were not required to understand the science for the technology to be effective. Decisions were made by a computer; they were relatively inexpensive and usable by workers with low educational levels. Embodied technology is the most suited to bulk commodity crops whereas information-intensive precision agriculture is most suited to higher value crops.

Widely adopted precision agriculture normally responds to some local need, it’s easy to use, and shows quick and highly visible benefits.

15.0 The application of precision farming technology for rural land and asset management

15.1 On the farm

Precision agriculture provides the tools to address the growing challenges facing agricultural production and land management in terms of the requirement to feed a growing population, whilst maintaining and protecting the natural resources and the services the former provide in the form of ecosystem services.

My report has considered the technologies that are available to measure 'in field' variability and the ways in which variability can be managed. The data collected from these technologies can be used to determine best practice on farm, accounting for variability.

The benefits of precision agriculture include:

- Reduced input costs
- Efficient allocation of inputs
- Reduced operation costs
- Reduced pollution through sustainable use of inputs.
- Improved crop yields and gross margins
- More efficient use of existing land area
- Providing better information for management decisions
- Providing better farm records which can be integrated with suppliers, processors and retailers

Precision agriculture is a major contributor to achieving sustainable intensification and sustainable land management.

15.1.i Addressing yield potential

Crop production needs to achieve its yield potential within a field and precision agriculture provides the technology to do this. It is clear that whilst we understand the key elements of variability and their impact on crop performance, further research is required to provide a more detailed understanding.

All farmers should try to address the yield potential of their crop production systems by addressing the issue of 'in field' variability. As producers have expanded field sizes 'in field' variability has increased.

As I saw in Australia, simple crop performance modelling tools such as Yield Prophet helped farmers and advisors to identify the yield potential for a field and manage inputs accordingly. A similar system is required in the UK that addresses UK climatic condition, accounts for variability and impact of inputs on the environment.

15.1.ii How to address the implementation of precision agriculture.

Precision agriculture is not about the most modern, most expensive equipment; it's managing variability on your holding within your existing resources, and can include planned machinery replacements to improve your ability to manage that variability. It is still agriculture but with an efficient approach to achieve yield potential whilst maintaining the natural environment and its ecosystem services.

At a farm level it is essential to identify whether variability is an issue and if so how it can be managed. The best way to manage this is to prepare a 10 year plan for adopting precision agriculture techniques, which considers what changes need to be made to the existing farming enterprise and what it will cost.

In preparing the plan you should consult other suppliers to the farm such as the machinery dealer, the agronomist and the agribusiness advisor to see how data on the farm can be managed and whether it can be integrated with any other data that is being collected - from machine telematics or by the agronomist etc. It is also important to consider how the data will be managed: whether through a consultant or using your own farm management software.

Not all the technologies are suitable for every farm and you need to assess the technologies that will help you address the variability issues you have on your holding.

15.1.iii Farm management information systems/ farm GIS

Systems have been available for some time to store and interpret field data collected from precision agriculture technologies such as Farmworks and Gatekeeper. Systems gradually becoming smarter and are now available for remote management of the farmstead. For example from the land owner's computer at his desk in London he can monitor the efficiency of his wind turbine and renewable energy output; he can monitor the grain temperature within the grain store; view the farm or estate CCTV footage and locate the farm machinery fitted with GPS technology.

There are many systems in development at the moment but still no single integrated management system that provides all the answers. Eventually we will be looking at one integrated land management system that brings together regulatory compliance, agronomy advice, environmental advice and meteorological data to provide more informed land management decisions and real time information about the land and crops being produced.

15.1.iv Integration of data in farm management

Yield mapping

The data from precision agriculture provides an essential tool for farm management. Yield mapping can be used to clearly assess the productivity of the land and where variability is restricting crop performance.

Profit maps

Profit maps map the spatial variation in profitability across a field. They allow managers to assess the land in terms of its profitability, which enables decisions to be made on whether low-profit or loss-making areas of a farm have underlying factors which can be managed using variable rate technology to improve profitability; or whether they require land drainage or whether to change the land use to provide environmental benefits. Yield mapping and profit mapping also provide useful ways of illustrating farm management issues to land owners or their advisors.

Digital elevation models

Digital elevation modelling on a farm can provide an added perspective to the landscape and often identify surface water collection issues that may affect management decisions.

Monitoring crop health

Regular passes over a field with a sprayer/tractor mounted sensor - such as the Yara N Sensor or remote sensing imagery - provides important information about crop heath during a season. It is important for making management decisions about crop nutrient applications and assessing yield potential. ''On the go'' sensors such as the Yara N sensor enable real time application of nitrogen but care must be taken when using such technologies as crop variation is due to a number of factors, not just nitrogen. In cases where little is known about the history of the land it may be more beneficial to interpret the biomass data together with other measured variables.

On farm trials

Precision agriculture technologies can also be used to carry out on-farm trials to test new management practices on your own farm. This was practised in Australia where farm managers wanted to assess the impact of varying nitrogen application rates and timing within a growing season. The trial plots were established, managed and harvested within the normal field setting, being identified by GPS.

Integration with suppliers and markets

Farm management information systems can now also integrate with supplier systems and, as seen with Farm365.net in section 10 of this report, farm information can be used for suppliers, such as the seed supplier company KWS, to provide recommended seed varieties and allow online ordering.

Increasingly farmers supplying larger food contracts for companies such as McCains are required to provide records of nutrient applications and the ability to demonstrate best practice in growing the potato crop. Precision agriculture will have an important role to play in demonstrating sustainable land management practices in the form of variable rate nutrient applications, variable rate potato haulm killing and variable rate irrigation.

Telematics and machinery management

As demonstrated in section 8.0, telematics provides the technology to manage farm machinery effectively. Farm machinery can be located on a computer from the farm office and monitored. If there is a problem the farm manager can speak to the operator to identify the cause of the problem and if necessary the dealership can carry out diagnostics remotely on the system in the field.

Environment

The data provides information to carry out a risk assessment of environmental issues on land, and locate mitigating management - such as buffer strips - to prevent any damage to the wider environment. Precision agriculture data can now provide us with important information on soil management - such as crop nitrogen requirement - and highlight the risks of leaching. This type of information should be used on farms to manage impacts of farming on the environment. More emphasis should be given to self-regulation as the data becomes available to manage and monitor natural resources essential for agriculture.

Regulatory compliance

With increasing regulation and the burden of record keeping, the technologies associated with precision agriculture provide more efficient record keeping systems, some of which can be automated based on data coming in direct from the field.

Education

Educating farm employees on precision agriculture and its applications on the farm is important to ensure they co-operate with efforts to implement the technology on farm. The data is reliant on correct calibration of machinery, and poor education of machinery operators or a lack of co-operation can lead to poor data. Agricultural colleges also have a role to play in educating the next generation.

15.1.v Adding value to services and maintaining market share

Precision agriculture provides a reservoir of data that is rapidly being accumulated by farmers and machinery manufacturers, which could be available for interpretation by them and other associated industries and land management professionals.

Precision agriculture data is an essential tool for maintaining market share for associated industries. For example New Holland provide precision land management software which also incorporates machine telematics. If this system operates efficiently it vastly increases the chance of the next tractor purchase on the farm being a New Holland tractor. This is the thinking behind the policy decisions of all the major machinery manufacturers.

Seed companies and agronomists are also using precision agriculture to maintain market share. For example Agrovista have launched a farm management information system this June - ‘Axis’ - as have Hutchinsons with ‘Omnia’. By providing these services they gain access to data about a farm and can recommend chemicals based on that data held in their system. Their thinking is also that, this way, you are less likely to use another agronomist.

For the same reason it is no coincidence that Monsanto purchased America's largest climate forecasting and big data specialist company in 2013 for $960 billion. Climate.com provides hourly reports on field-level conditions like precipitation and wind speed; it emails and text alerts when thresholds are exceeded, and even offers a mobile app. The data is based on field-specific and highly detailed weather forecasts that can be used to make management decisions related to seeding times. Monsanto are using this data to develop a farm management system to support the sale of seeds and chemicals.

Farm contractors can even add value to their services by providing precision agriculture services such as N Sensor data, data management and interpretation.

15.1.vi Land assessment and value

When deciding on a land purchase - or any new farming venture on new land, either by tenancy or contract/share farming - it is important to consider the variables that will affect the productive potential of the land. For example geo-referenced nutrient status; soil type zones; soil compaction; past pest and disease locations such as blackgrass - all of which provide important information regarding the productive capacity of the land and therefore its value.

15.1.vii Summary

There are significant benefits attached to the adoption of a precision farming system but the system needs to be planned carefully. Data collection is the easy part but analysis and interpretation of the data is harder. Either a good farm management information system with a knowledgeable operator is required, or an external consultant with relevant qualifications.

External consultants can make adoption of precision agriculture more straight forward but farmers must ensure that their own knowledge about the land is shared with the consultant, as otherwise factors affecting variability - such as previous land-use may be missed.

Sensors used in precision agriculture always need to be calibrated as do auto steer systems. Although in some instances this is time consuming such calibration is essential to providing valuable data about crops and the land. **Care should be taken to ensure that agricultural decision making is not automated to such an extent that practical agricultural knowledge is lost. Precision agriculture is a tool for agricultural production and is not a replacement for practical knowledge and the physical inspection and monitoring of crops.**

15.2 Precision agriculture and the natural environment

"Biodiversity" describes the variety of life on earth from human beings to microorganisms; the diversity of all the habitats in which they live; and the genetic diversity of individuals within a species. These form part of the global ecosystem, the Earth's entire collection of living things, and the environment in which they live. Biodiversity is threatened by:

- **Loss of habitat and fragmentation**, such as clearance of native vegetation for agricultural land and draining wetlands thus damaging the natural habitats and organisms within them.
- **Invasive species** – non-native species cause significant problems to ecosystems they invade and can come at great expense to agriculture forestry and fisheries: for example Japanese Knotweed.
- **Pollution** - any chemical in the wrong concentration in the wrong place can poison species or damage habitats.
- **Climate change -** will affect the climate surrounding a habitat and lead to a change in the abundance and distribution of individual species.
- **Over exploitation** - humans can damage a natural ecosystem through exploitation of biodiversity - for example excessive fishing of a particular species or excessive deforestation with no new planting - which can lead to the removal of a species from an ecosystem and an unbalancing of the system

Ecosystems are the interaction of living organisms with their environment, which operate as a whole system. They provide services known as ecosystem services as follows:

Supporting	**Providing**
• Nutrient cycling • Soil formation • Primary Production	• food • timber and fuel • textiles • medicinal products • fresh water
Regulating	**Cultural**
• climate regulation • control floods • pollinate crops • purify our water • absorbs CO2 gases • erosion	• aesthetic landscapes • education • cultural heritage • a healthy environment • recreation and tourism

Agriculture relies on eco system services such as soil, water and nutrient cycling for food production. It can directly impact on biodiversity through over application of nutrients, damaging soils through compaction which will, in turn, damage ecosystems and eco system services. The challenge is to ensure that agriculture does not impact on biodiversity or ecosystems resulting in a reduction of ecosystem services.

But do we know how to manage the land to enhance ecosystem services? For example Professor Lynn Dicks at the University of Cambridge was asked what crop rotations are best for biodiversity and she believed that we do not know the answer to this yet. Speaking at the UK Cereals Event Professor Lynn Dicks commented that more needs to be understood about how plants interact with their environment; there is a need to integrate Bid Data with practical applications to deliver to users such as farmers and land managers. More needs to be done to understand interactions within ecosystems. For example one third of crops produced are dependent on pollination, but this is an area we simply do not know enough about. What opportunities are there to enhance pollination and what impact may this have on crop yields?

We know we can, through the use of precision agriculture and applying the right amount at the right place at the right time, reduce inputs such as nitrogen that may damage biodiversity.

15.2.i How does precision agriculture help the environment?

Precision agriculture now provides the ability to monitor accurately - at a specific location within a field - soil properties; nutrients; water; weather; pests and diseases; and their impact on the crop or biomass quality of the surrounding environment. This information is important to manage biodiversity and ecosystems as it provides valuable information on the biodiversity an area is capable of supporting, and would enable land management to be tailored to enhance ecosystems and their services.

Vast amounts of data can now be collected as base information at a farm level through precision agriculture technologies, but ecological intelligence and research needs to be improved to understand what land management practices can be used to enhance ecosystem services and protect biodiversity unique to the environment of that farm within a regional landscape.

Environmentalists and agriculturalists need to work together to ensure the needs of food security and the environment are balanced, through sustainable intensification. They need to find ways of sustainably managing biodiversity within agricultural ecosystems, and at the same time being within the context of profitable commercial farming.

The University of Cambridge is working on research entitled '*Supporting Ecosystem Services on Commercial Farms: Using Evidence to Inform Land Management Decisions*". This research forms part of DEFRA's sustainable intensification platform. It aims to recommend how commercial farms in the UK can be managed to support biodiversity and ecosystem services *without* compromising on yield or profit. The project will try to identify management actions that maximise ecosystem service delivery on farms whilst retaining viable profits, and will also aim to develop agri-environmental measures to support beneficial insects (those providing pest control and pollination services) on different farm types.

Precision agriculture alone is not the key to sustainability but is part of sustainable precision land management.

15.2.ii Targeting conservation

Farmers and land managers should be able to appraise the ecosystem services being utilised - and at risk of damage by their farming system - and thus consider targeted management practices on their holding that enhance the ecosystem services and potentially increase agricultural output: for example providing habitats for bees for pollination.

Currently EU environmental schemes do not support agri-environmental options that potentially also provide commercial benefit to the agricultural enterprise. For example field margins created with mixes to provide habitats for crop pest predators cannot be funded by any EU scheme. This narrow minded thinking is not allowing agriculture to enhance ecosystem services and is limiting the potential for farmers to manage the natural environment and also achieve the objectives of food security.

The introduction of the new EU Common Agricultural Policy Reform greening measures in 2015 will do little to enhance current ecosystem services due to the blanket, rather than targeted, approach. Research on nutrient leaching in Wisconsin, America, highlighted that despite a blanket agri-environmental scheme only 10-15% of farmers within a region were creating any conservation issues from nutrient leaching. 60% of farmers were taking part in the schemes and achieving absolutely nothing. From this Pete Nowak, Professor of Environmental Studies at the University of Wisconsin, in a concept referred to as precision conservation, recommended targeting the 10-15% of farmers (mentioned above) with management options to reduce leaching.

15.3 Precision agriculture and rural land and asset management

Precision agriculture provides us with vast amounts of information that have not been available before. The data has a lot to tell us and we need to utilise it to make informed management decisions. Precision agriculture does not stop at the farm gate.

As the productive potential of land becomes more reliant on interpretation of this data produced from the land, industry professionals must ensure they can understand the *implications* of the data to appreciate the true value of the land they are managing or selling.

15.3.i Precision agriculture and land assessment

There is no doubt that, as the uptake in the technology increases, current and historic data will be required by any farmer or corporate wanting to make a commercial decision on the purchase of land. In the sale of any business you wouldn't make the purchase unless you had seen the accounts and this will become the same with precision farming data in land transactions.

When deciding on a purchase of land or any new farming venture on new land, either by tenancy or contract/share farming, it is important to consider the variables that will affect the productive potential of the land. For example geo-referenced nutrient status, soil type zones, soil compaction, past pest and disease locations such as blackgrass.

When I met Ian Delmenico, an agronomist from the Mallee region of Australia, he was already carrying out soil surveys for clients using electro conductivity to assess the suitability of soils on land available to purchase or rent. Ian would model the viability of a purchase and parameters for the price that should be given to ensure a reasonable return.

There is real value in the data that helps real commercial decisions to be made about farming the land. It also has the potential to increase the efficiency of agriculture. If, for example, you were looking to sell your farm you would want your nutrient management to be showing the correct indices, and past weed and disease burdens shown as a minimum; otherwise you could affect the value of the property. The management of the land in relation to the ecosystem should be similarly reflected.

The value of the data could also be reflected in the value and demand for the land. Land is more valuable if you are buying a known rather than an unknown. For example if a digital elevation model highlights areas where surface water may collect and affect the productive potential of the land, technologies mean that a scheme can quickly be modelled and appraised financially, which could affect a decision to take on the land.

The question has to be asked: '*Would farmers really want to make this data available to purchasers or pass it on to the next people farming the land*?' My opinion is that this requirement will be more demand-led than automatic, and gradually it will become accepted that this information *has* to be available to purchasers. In situations where data may not be available surveys could be carried out independently or remotely using UAVs, planes or satellite imagery without the need to actually access the land. Historic satellite imagery will also be able to provide a historical context.

15.3.ii Precision agriculture as a tool for land managers.

Within the UK there are a number of forms of land tenure; whether a traditional Agricultural Holdings Act Tenancy, a modern Farm Business Tenancy or Contract or Share Farming arrangement. Within these, precision agriculture provides its own potential applications supplying valuable information about land being farmed outside the direct control of the owner.

End-of-tenancy compensation under the Agricultural Holdings Act 1986 permits an outdated calculation for residual manurial values under the Agriculture Calculation of Value for compensation (Amendment Regulations SI 1983 No1475). However, given the data that can now be collated on some farms, a more modern approach must be considered.

When determining a rent review for an Agricultural Holdings Act 1986 Tenancy, regard must be had to the productive and related earning capacity of a holding. The tools of precision agriculture can be used to assess this, considering relevant factors such as digital elevation models for identifying areas of poor drainage, poor soil types, areas of limited yield potential or other limitations of a farm that reduce its productive and related earning capacity.

Development of yield potential models for cropping will also help in addressing the issue of productive and related earning capacity.

There are limitations to imposing new clauses within a historic tenancy unless there is reason to vary a lease - such as on succession - but the availability of data between the tenant and the land owner should be considered as a new clause if appropriate.

In the case of a Farm Business Tenancy, the sharing of precision agriculture data between the parties will allow land owners to ensure that the nutrient status or soil properties are not being compromised, and provide a course for redress in the form of dilapidations if the tenant has failed to maintain and manage the land as required by the tenancy agreement.

For contract farming and share farming operations precision agriculture technologies make management of the arrangements easier as data can be readily available. One limiting factor in the uptake of these agreements is the administration of them. However the advances in the transfer of data and farm management information systems allow parties to the agreement to have access to the data remotely at any time, both day and night, for their consideration. For example a contract farming operation can be overseen by the landowner from his desk in London while the contractor is actively carrying out the work. The availability of data such as soil moisture sensor data remotely, such as the seen at the CSIRO smart farm, also allows for management decisions to be made off the farm.

15.3.iii Transfer and sharing of data between occupiers and land owners

The data produced from precision farming technology also provides valuable information about the productive capacity of land and what could be done to enhance its productive capacity. In my opinion it is therefore valuable information when selling a farm, land, or letting or establishing a contract farming arrangement. The collected data will belong to the farmer but I would consider that maintaining a right to view any precision farming data on let land or contract farmed land essential.

At an estate level it is important to integrate data on a farm level with that of an entire estate to assess efficiency of land use and management and overall impact on the environment. On an estate, use of precision land management on an individual farm level will not on its own constitute sustainable land management of the whole estate.

It is important to formulate a protocol on the use of geo-referenced farm data as it will have been obtained in the course of farming the land. Landowners should have access to this to utilise the information going forward, rather than having to start rebuilding data again every time there is a change in land occupation.

Agreements should consider clauses for the data obtained during the normal course of farming the land to be shared with, or be available to, the land owner.

15.3.iv Natural environment

Rural estates, landowners and farmers are now required to be socially and environmentally responsible. Section 15.2 has considered how the data can be used to manage and monitor the natural environment and the ecosystem services. In order to provide sustainable land management within the UK, the maintenance and enhancement of the natural environment and ecosystem services need to be considered. Inevitably carbon off-setting and bio diversity off-setting will provide some form of financial consideration for this.

15.3.v Forestry management

Commercial forestry has adopted the same key technologies of precision agriculture through precision forestry, and it is a key area of development within the industry. Remote sensing is capable of detecting variations in type, density and biomass of woodland which can then be mapped on geographical information systems to assist in management.

As part of my study I visited Cawdor Estates in Inverness, Scotland, who own 6,390 ha of commercial forestry as well as advising on a further 18,000ha of forestry through Cawdor Forestry. My case study attached in **Appendix 1.0** demonstrated the importance to forestry of the developing technologies of GPS, GIS and remote sensing.

15.3.vi Moorland management

The three key technologies of precision agriculture also apply to moorland management. Remote sensing provides opportunities for remote management and monitoring of large areas of open land; such as moorland mapping, grips, vegetation type, hazards, bogs, holes, protected species, etc., to provide a permanent record of these features.

Ground penetrating radar can be used on moorland to produce accurate maps of peat depth. The data can be used to inform construction plans and environmental impact assessments on wind farm developments, management of water catchments and the methodologies used in moorland restoration projects.

Data from moorland management practices can be integrated with remote livestock management practices such as geo-fencing to control livestock grazing to conserve and protect the natural environment. Digital elevation modelling can also be used to enhance the sporting and natural environment elements of a grouse moor.

15.3.vii Adoption of new surveying techniques.

Unfortunately in the world of ‘big data’ a paper map and a measuring wheel need to be updated with a GPS measuring device and a computer based geographical information system (GIS).

The technologies discussed earlier in my report will all need to be considered as potential surveying techniques for land managers. Remote sensing will be an important tool for land managers as it provides access to data remotely, i.e. without the need to access the land. It can be used in situations where access is not possible; such as no right to enter the land or difficult terrain.

The development of technologies to support the use of remotely sensed information for surveys will mean that it becomes an essential surveying tool, but not necessarily a replacement for being on site and inspecting things for yourself.

Unmanned aerial vehicles (UAVs) provide a platform for remote sensing. Increasingly surveyors are using UAVs as a data source for land surveys and information gathering on land use. They are also used for inspecting buildings and infrastructure such as power lines in remote areas. UAVs are also being used to create marketing videos for farms and estates to provide an all-round perspective of a property for marketing purposes.

The ability to geo-reference land features - such as fences, hedges and trees - using GPS will also be invaluable. It is already being used to carry out tree surveys on estates to manage and record the condition of individual trees for health and safety purposes. With an increasing EU requirement for the protection of environmental features on land it will also enable land managers to record environmental features for management.

LiDAR is already used in building surveying but has potential applications on farms and estates to provide a 3D representation and record of the natural environment.

The new technologies alone have implications on surveying techniques but the data generated from precision agriculture also needs to be interpreted by surveyors when assessing the performance of a farm, assessing that the land is being managed effectively and, in the case of agribusiness, advise any areas where management can be improved.

15.3.viii Crop loss

The data also becomes useful when considering crop loss claims for insurance purposes for third party activity across land. Yield mapping can demonstrate a yield variation. Remote or proximal optical sensing can measure crop biomass which will provide valuable evidence to support or validate a crop loss or insurance claim.

15.3.ix Regulatory compliance

Government bodies and the EU are already using remote sensing technology to monitor regulatory compliance for both the Single Payment and Environmental Stewardship schemes. As the technology advances, measurements are becoming increasingly accurate, reducing the need for physical inspection. The advantage is that precision agriculture is capable of providing more data than government bodies can obtain and farmers and land managers need to utilise this to advance self-regulation rather than waiting to be regulated.

15.3.x Off -setting schemes

Carbon off-setting and biodiversity off-setting are schemes that have been proposed and are being trialled within the UK. The ability to use accurate geo-referencing will enable these types of schemes to be monitored and regulated more effectively.

15.3.xi Summary

Precision agriculture undoubtedly provides us with data to make more informed management decisions. The technology has a lot to tell us and we need to utilise it. As farmers start to manage land in a more precise and zoned way, land managers should follow. **Precision agriculture not only contributes to the sustainability of food production but also to sustainable land management.**

We now have the tools to provide more efficient land management, and can utilise data and resources that are now available to meet future sustainable land management targets.

There is no option but to utilise data within land management to improve practises, adapt and become more efficient.

16.0 Conclusions

1. Agriculture and land management have some significant challenges ahead. There is a need to feed a growing population and manage the environmental impact of that growing population, whilst working with a limited supply of land.

2. Precision agriculture provides the technologies to address 'in field' variability of land and consider the yield potential of the land being managed. Platforms for obtaining data through optical sensing include: satellites, manned and unmanned aerial vehicles, and agricultural machinery carrying out day-to-day operations, or robots.

3. Optical sensors can be used to assess variability, monitor crop health and inform farm management decision-making on how to reach the yield potential for that crop, whilst accounting for variability. The sensors can also be used to monitor environmental impact and ecosystem services thus helping farmers and land managers to achieve sustainable intensification.

4. Precision agriculture and precision conservation, or management and enhancement of ecosystem services, combine to form precision land management.

5. The data collected from land is important for immediate decisions and for future generations. The data can be used for research, on-farm crop trials and to model and simulate crop production; whilst accounting for all variables, including changing weather, to ensure that management throughout a season achieves yield potential.

6. The data from precision agriculture can be used to assess return on investment for land and make more informed decisions about land purchased, or new land lease arrangements. This could lead to a price adjustment where current land values exceed the productive potential of the land.

7. The data will also provide a better picture of the condition of the land, and therefore well maintained land with good nutrient status and organic matter content will be more valuable and the better farmer rewarded.

continued on next page

8. The data will enable more informed decision making with farm management information systems that can determine grazing intensity based on satellite imagery of the pasture. Farmers and land managers will be better positioned to assess their own impact on the environment - such as nutrient leaching and water quality - and need to use this to regulate themselves and demonstrate their ability to do so (as I saw in New Zealand) rather than waiting for EU and UK regulation increase the burden of farm regulation.

9. Ownership of data produced from the land will be very important. Transfer of the data between land occupiers will be key in ensuring the data can be used to its full potential for production purposes in agriculture. However it is essential to ensure that farmers' data is not sold on without their knowledge.

10. From a land management perspective precision agriculture data will provide the information required to sustainably manage land use, protecting land that is important for food production and land that is important for biodiversity and the provision of ecosystem services.

11. We now have the tools to provide more efficient land management, utilising data and resources that are now available to meet future sustainable land management targets. There is no option but to utilise data within land management to improve practices, adapt and become more efficient.

12. Other associated industries have potential to use data to add value to their services and need to address ways in which the data can be useful for their relevant market sectors, such as food traceability. They also need to integrate with other advisors to the same customer. Agronomists and machinery dealers would pass each other at the farm gate but now they need to stop and talk to each other, to advise their client correctly.

17.0 Recommendations

1. Farmers, land managers and advisors need to be informed of the benefits of precision agriculture technologies, and the practical application of these technologies to address the yield potential of land.

2. Further agronomic research is required to understand the impact of variability on crop production and how it can be managed to reach yield potential, together with further engagement of agronomic advice for precision agriculture.

3. UK crop models and simulation software tools are required that account for geo-referenced data on 'in field' variability, to assess yield potential of land and potential return against inputs and environmental impact.

4. Farmers and land managers need to consider the wider tool kit of technologies available to them for measuring and addressing variability.

5. Farmers and land managers must use the data to regulate themselves and demonstrate best practice, rather than waiting for the industry to be regulated.

6. Funding available through the EU Rural Development Programme needs to be targeted at the adoption of precision farming technologies which are used to address yield potential and maintenance or enhancement of ecosystem services.

7. Further research is required into the relationship of ecosystem services with agricultural production, such as pollination, and what management practices are required to enhance ecosystem services. This can be achieved by utilising data collected from precision agriculture.

8. Precision conservation should be considered within the UK landscape to manage water quality within catchments.

9. Industry professionals and associated industries need to remember that precision agriculture does not stop at the farm gate. The data has a lot to tell us and it will have an impact on your advice to farmers and land managers. For rural land and asset management the ability to identify and measure factors that affect the productive capacity of land will have an impact on land values and must be considered. For legal advisors the transfer of data on the sale of a farm will also need to be considered.

10. A UK or EU protocol is required that sets out how agricultural data is to be managed and transferred between land occupiers.

18.0 After my study tour – where are things going now?

From my Nuffield Farming Scholarship study I have learnt a lot about the technologies that are available through precision agriculture for both farmers and land managers, and the application of those technologies for rural land and asset management.

In order to improve the uptake of precision agriculture there needs to be a greater understanding by farmers, agronomists and land managers of its application in the UK. Having seen the success of the South Australian Precision Agriculture Group, I am in the process of establishing a local interest group on precision agriculture, which will act as a platform for farmers, agronomists and other associated industries and industry professionals to improve understanding and adoption rates of precision agriculture technologies in my local area. If it works effectively then is should be repeated nationally,

On a professional level my tour has demonstrated to me the importance of maintaining geo-referenced information and the use of geographical information systems. In our office, after numerous attempts at explaining the concept of GPS and GIS in the boardroom, we now have a handheld GPS device and geographical information system which I use on a day-to-day basis for farm mapping and field data collection. Senior partners now recognise the relevance of such data to their professional work.

I intend to promote my findings with my professional associations: the Royal Institution of Chartered Surveyors and the Central Association of Agricultural Valuers, as well as to the wider farming community.

The opportunity to complete a Nuffield Farming Scholarship will enable me to provide a broader range of services to my clients, through agri-business advice that educates and supports farmers and land managers in the adoption of precision agriculture technology: including services for data collection, interpretation, analysis, application and management.

As new technologies constantly become available, precision agriculture is a continually developing subject. I hope to continue my study of the subject including travelling to North America to investigate further the concept of precision conservation and how it could be applied in the UK.

I believe my study findings also need to be considered at a policy level and I have started discussions with the Rural Payments Agency regarding the integration of precision farming data with their new online mapping system. This could perhaps include remote sensing services, and support the development and uptake of precision agriculture in the UK and thereby sustainable land management.

Davina Fillingham

19.0 Executive summary

Agriculture and land management have significant challenges ahead. A growing population needs to be fed and the environmental impact of that growing population managed, whilst working with a limited supply of land.

Precision agriculture is nothing new but is constantly developing with the introduction of new technologies. Recent advancements in optical sensor technology have created an ability to manage 'in field' variability 'on the go' using 'real time' data from the field, and wireless sensor networks provide the ability to remotely monitor and manage field operations such as irrigation.

Whilst the technology is advancing rapidly, it was clear to me that UK farms were not exploring the full potential of precision agriculture.

I wanted to investigate three key elements around my subject: the range of precision agriculture technologies available to farmers and land managers; how they can utilise data from precision farming technology; and how professional advisors can utilise the data produced from the land for rural land and asset management.

My study took me to the 2013 European Conference on Precision Agriculture held in Spain; the Netherlands, France, Germany, Australia, New Zealand and UK to look at the latest developments in precision agriculture technology and their practical application, together with research projects and other related industries such as forestry.

Precision agriculture clearly has the potential to address the challenges facing agriculture and land management. The 'in field' variability identified by precision agriculture can be addressed to ensure land is managed to meet yield potential, thus improving farm output.

The ability to measure the natural resources on which agriculture is dependent - such as soil nutrients, soil moisture and organic matter - is made possible with the advancement of precision agriculture technologies. From this we can measure and monitor our impact on the natural environment including ecosystems and ecosystem services. There will be a greater emphasis on the value of these natural resources.

Further agronomic research is required to understand the impact of variability on crop production and how it can be managed to reach yield potential. Crop models and simulation software tools that account for changing climatic conditions through a season are required to assess the yield potential of land, and assess the potential return against inputs as well as the environmental impact.

Data from precision agriculture technologies is and will be increasingly important for the advancement of production and land management. An EU or UK protocol is required that sets out guidelines on ownership of farm data and how it is to be managed, and transferred between both land occupiers and other interested parties.

We now have the tools to provide more efficient land management and to meet future sustainable land management targets. There is no option but to utilise data within land management to improve practices, adapt, and become more efficient.

Precision agriculture does not stop at the farm gate and the data which it generates can be used by associated industries. Precision agriculture is part of a wider landscape concept of precision land management.

20.0 Acknowledgements and Thanks

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The people I have met on my study tours have been invaluable in conducting my study and I am grateful for their time, open discussions, challenging conversation, interest in my topic and warm welcome and accommodation on my travels.

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Netherlands
Trimble International Representatives
Frits Van Evert - Wageningen University
Dr Corne Kempenaar - Wageningen University
Eldert Van Henten - Wageningen University
Jochen Hemming - Wageningen University

Australia
Brett Whelan – University of Sydney Precision Agriculture Laboratory
Amy Crosby - University of New England
Zac Economou - University of New England &Precision Agriculture research Group (UNE)
Sundown Pastoral Company

National Centre for Engineering in Agriculture – South Queensland University
Cheryl McCarthey
Dr Matthew Tscharke
Alison McCarthey
Dr Malcolm Gillies

John Deere - Chesterfield

Peter Kaylock - Nuffield Scholar and Farmer
Ian Delmenico - Agronomist

Landmark Australia
David Cook – Nuffield Farming Scholar and Farmer
Philip Hubbard - TopCon precision Agriculture Australia
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Nick Berry - University of South Australia
Jane Greenslade – Nuffield Farming Scholar

New Zealand
Craige Mackenzie – Farmer , Nuffield Farming Scholar
Roger Williamson – Foundation for Arable Research (FAR)
Armin Werner - Lincoln Agritech
Jess Roberts – Lincoln Agritech

UK
Prof Simon Blackmore – Harper Adams University
Dr Mark Rutter - Harper Adams University
Clive Blacker – Precision Decisions
Steve Conolly– Cawdor Forestry
Amy Taylor – Cawdor Forestry
Tom Luthman – John Clegg & Co Chartered Surveyors
Peter Robinson – Trimble
Hamish Wilkie - Trimble
Aimee Dawson – Sustainability & Quality Manager Birds Eye Limited
Chris Harry Thomas – URSULA Precision farming consultant

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22.0 Appendices

See these Appendices on the following pages

APPENDIX 1.0

GPS, REMOTE SENSING AND GEOGRAPHICAL INORMATION SYSTEMS IN FORESTRY.
CAWDOR ESTATES & JOHN CLEGG & CO INVERNESS SCOTLAND.

Cawdor Estates lies east of Inverness, Scotland and extends to approximately 23,400ha (58,000 acres) with approximately 6,390 ha (15,800 acres) of primarily commercial forestry, growing nearly 2000 ha of scots pine, 600 ha of Sitka Spruce, 570 ha of Beech along with Larch Pine and Caledonian Scots Pine. Cawdor Forestry manages a further 18,000 ha of woodland for landowners across the UK.

Cawdor Castle - Inverness, Scotland

Steve Conolly heads Cawdor Forestry and when he started on the estate approximately 20 years ago the only information he had was provided by a paper map which mapped forestry compartments, but it did not map the species within the compartments.

Whilst his predecessor knew how the compartments were mapped there was no central reference for estate employees and contractors. Steve set about mapping the woodland using black and white aerial photography and GPS to provide the base maps which are used today.

A forestry company or agency that does not have up-to-date, accurate information about its woodland cannot make effective strategic decisions. They require detailed information on woodland boundaries, site quality, age classes, conditions of topography and soils and the location and condition of infrastructure. Increasingly, non-timber resource information such as recreation potential and the condition of wildlife habitat is also becoming important for strategic planning. All of this information is combined to produce a timber inventory.

Forestry uses the three main elements of precision agriculture within precision forestry.

1. **Global positioning systems** (GPS)
   The same GPS services provided for agriculture are used with forestry. They enable data collected from the ground or remote sensing to be geo-referenced and mapped using GIS. Unlike agriculture there is no requirement for sub-meter accuracy therefore Differential GPS or uncorrected signals providing 2m accuracy suffice.

2. **Remote Sensing**
   This is a fundamental too: for capturing forestry data remotely over large areas of often undulating terrain. The data can be used for determining ground cover, vegetation types, soil, streams etc.

3. **Geographic Information Systems (GIS)**
   This allows the data collected from remote sensing and any ground surveys to be mapped and analysed, to display and publish spatially referenced data. GIS is more than a mapping system, it provides advanced analytical capabilities which enable managers to analyse complex situations. As with agriculture it is possible to "overlay" map layers representing factors which in the case of forestry will be: timber classes, soil types, and topography. This information can then be used to make important decisions on factors such as replanting species etc.

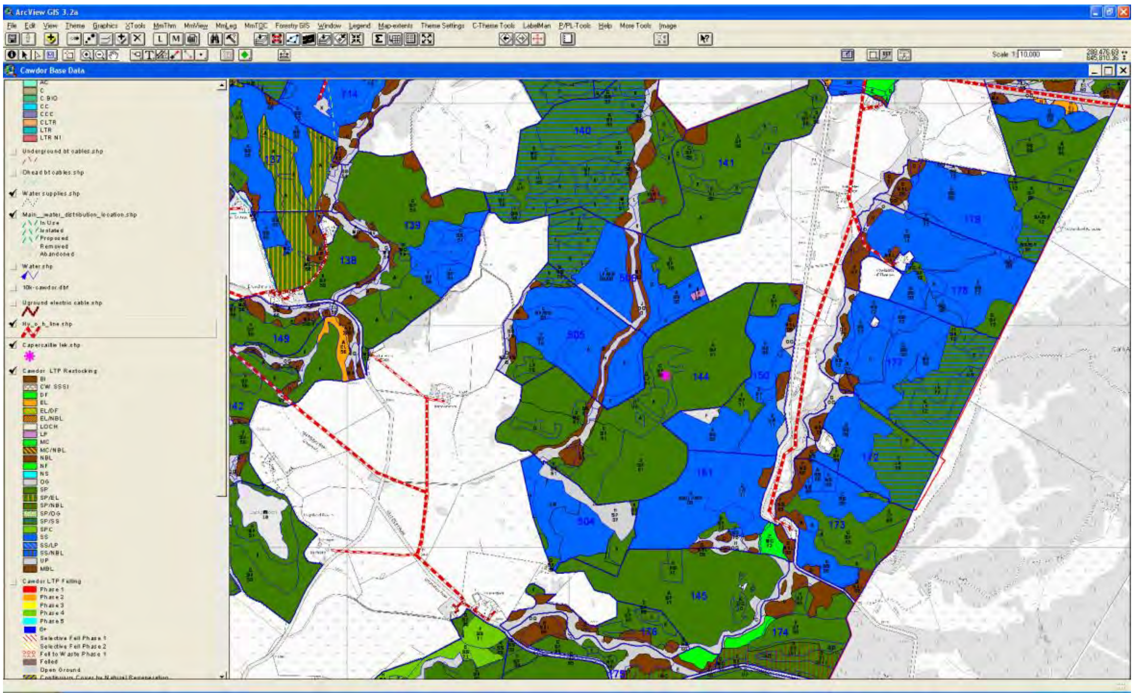
Precision Forestry is a combination of methods by which we can accurately determine the characteristics of forests, treatments, biodiversity preservation or recreational opportunities at the stand, plot or individual tree level, as well as using individual tree level assessments for simulation and optimisation models of forestry management in decision support systems.

At Cawdor Estates the woodland compartments and species are all mapped on a geographical information system known as ArcGIS. This is a common platform for GIS and is used within many industries including agriculture. It is expensive and needs someone trained in using the software to operate the system. Behind the GIS software is a database which stores all the information regarding the relevant compartments and species. This is used for recording species, management objectives e.g. commercial or amenity, projected yield, together with projected thinning and felling dates to help prepare budgets.

Whilst I was in Scotland I also visited Tom Luthman who is a GIS forestry specialist for John Clegg & Co Forestry based near Inverness. He also showed me the ways in which GIS systems are used in forestry to map the following features:

- Land area
- Planting compartments and species
- Archaeological

- Landscape
- Ecological such as waterways and wildlife
- Soil types e.g. peat. Where peat is more than 50cm deep trees will not grow and it results in carbon release into the environment.
- Road infrastructure & rides
- Power lines



Screen Shot from Cawdor Estates Forestry Arc GIS software showing plantations by species.

Forestry is a long term investment and therefore budgeting is an important factor in managing the returns on the investment. The database also stores all the information for forestry certification (FSC, Forest Stewardship Council). This is the equivalent of farm assurance for forestry.

Air surveys are carried out by Caledonian Air for £1/ha to provide geo-referenced aerial photography of new plantations that come under management; or when surveys are required of existing plantations to look at felled areas to consider restocking - the surveys may identify areas of gorse and broom growth which affect restocking. The images are uploaded into ArcGIS for interpretation and measurement.

When applying for a forestry licence the Forestry Commission requires information regarding the location of the site, access points etc., and this information can be easily obtained from the GIS system if the information has been correctly gathered and mapped in the first instance.

When selling timber Cawdor Forestry sell standing timber by tender and within the tender pack they need to provide information on the location of the compartment that is to be felled or thinned together with information on access, power lines from a health and safety aspect, and other factors that may affect the felling or timber extraction process. Capercalli are protected species and their presence on a site restricts operations in terms of time of year and distance from the lecs (nests) which contractors obviously need to be aware of.

The GIS system enables all this information to be stored in one place and either sent in a digital form to the contractor for use on his machinery or, for the less sophisticated contractors, printed off when required. On some occasions the estate provides the contractor with one of their handheld GPS devices, which have the mobile version of ArcGIS loaded on them, so the contractor can direct himself to the compartment, map the access route he has taken and if, for example, felling map the exact area he is felling.

Harvest machines have the ability to cut timber to specific lengths during harvest. The timber mill can send instructions to the harvest machine's on-board computer to satisfy order requirements, rather than simply cross-cutting individual stems to appropriate lengths that then need to be sorted at a later date. Yield information can be monitored remotely from the mill office and once that order has been fulfilled, details of the location of the roadside location and quantity can be sent to the hauliers for them to collect the timber. The specification of the next order can be sent to the machine and the process can be repeated again.

The data collected from harvesting in relation to yield and areas felled will provide important information for the next steps in the management of the forestry and needs to be available to the forestry owner and manager. It can be used to assess whether, in the case of a contractor, felling has been carried out in accordance with the felling licence and the contract with the forestry owner. Continuous timber inventories are of course essential, and models should also be developed for projecting growth and yield into the future so that strategy alternatives can be tested using computer simulation models.

Timber harvesting machine

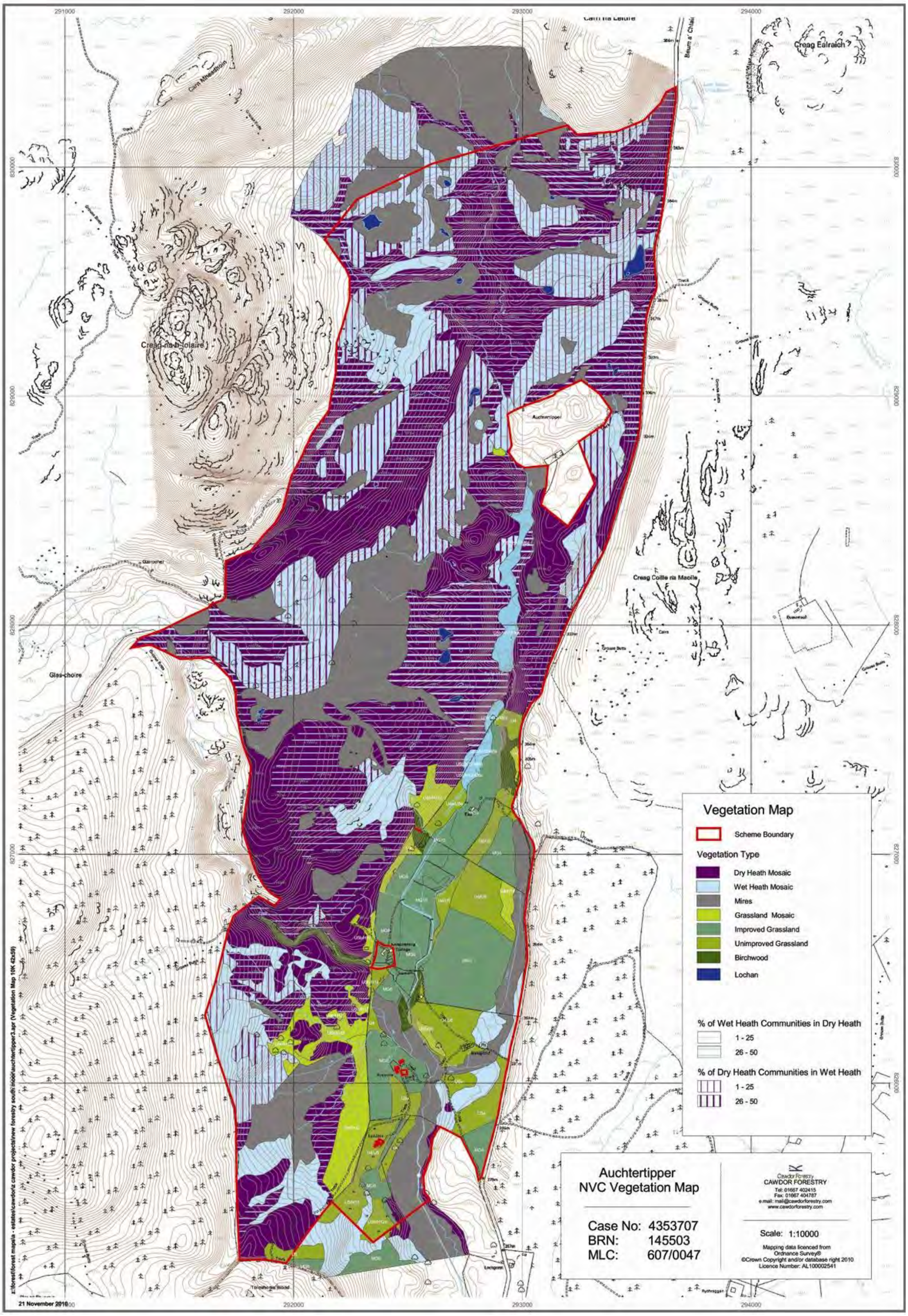
The use of real time data transfer is important for this and, whilst it has a lot of potential, a lack of telecommunications coverage in remote areas can be a limiting factor.

At Cawdor Estates contractors are not fully automated yet. The equipment is capable, but the operators aren't. Steve Conolly was hoping that Komatsu were going to work with the estate and one of the contractors to get the on-board computer on the latest Komatsu machine up and running, which will assist in data management on the estate. Once operating it is likely that contractors with this equipment will be preferred over others due to time saving, collation of information and recording.

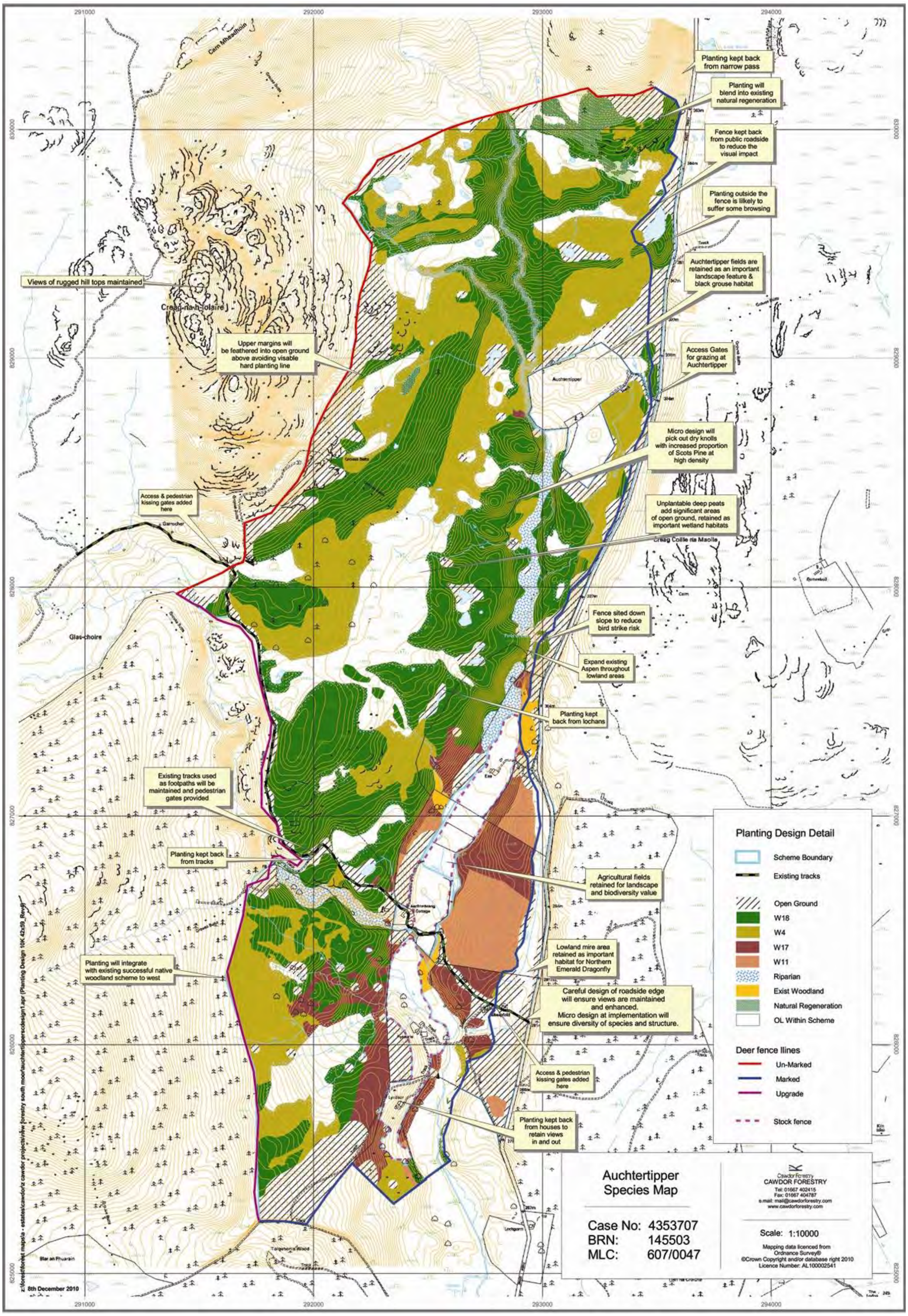
Information on past yields is important for restocking decisions and is useful information that, if it can be geo-referenced, can help in restocking decisions, as well as information on wet holes etc. Cawdor Forestry ask contractors to mark any wet holes when restocking so that these can be excluded from the funding claims, as they would be invalid.

Timber felling in Scotland

When looking at new planting, remote sensing technology, GPS and GIS have to be used to identify variables, as in agriculture. In one example Steve showed me, they had to assess current vegetation cover and soil type to plan a new planting. On the next page is a GIS prepared plan showing existing vegetation cover and, following on from that, the detailed planting plan mapped on GIS software. GIS enabled the layers of data on existing vegetation cover and soil type to form the base of the new planting map.



Existing vegetation plan prior to planting (Source: Cawdor Forestry)



Final planting scheme (Source Cawdor Forestry)

As with agriculture, LiDAR can be used in enhance forestry inventory data for it can be used to model forest cover, understory vegetation, and the ground surface. Airborne or aerial LiDAR systems are capable of covering vast tracts of forested land and allow partial characterisation of vertical and horizontal structure. Ground-based or terrestrial LiDAR systems complement aerial systems, capturing the finer geometrical, branching topology and biophysical attributes of the various forest elements. The data collected by both types of systems can be used to generate statistically-based estimates of key inventory variables, including tree height, volume and base area, and even fibre attributes linked to wood quality.

As mentioned earlier in my report, Treemetrics from Ireland are using remote and ground based LiDAR to assess timber volume and timber straightness within commercial plantations.

LiDAR had not been adopted at Cawdor Estates yet but Steve Conolly agreed that it does have potential. At the time of writing this report it does not appear to be a technology that has been adopted in the UK yet but, as timber values are now on the rise after years of depressed values, perhaps there is potential for more investment in technologies such as LiDAR.

Cawdor Forestry is using a modelling system to model the impact of new plantations on a landscape. The Forestry Commission increasingly like to see imagery which shows the potential impact of planting on a landscape. Information from the GIS system can be used to model and illustrate a new plantation within a landscape over a set time period.

Summary re precision forestry
Precision forestry management practices are increasingly becoming an essential part of commercial forestry management: capable of providing accurate forestry inventories, providing more accurate assessments of yield potential and future timber volumes for better business planning, the ability to manage operations in large open areas, and mapping and managing environmental features requiring protection. All the data becomes important in valuations of the planation and assessments of insurance values.

There are a lot of similarities between precision agriculture and precision forestry, each of which addresses variability within a landscape.

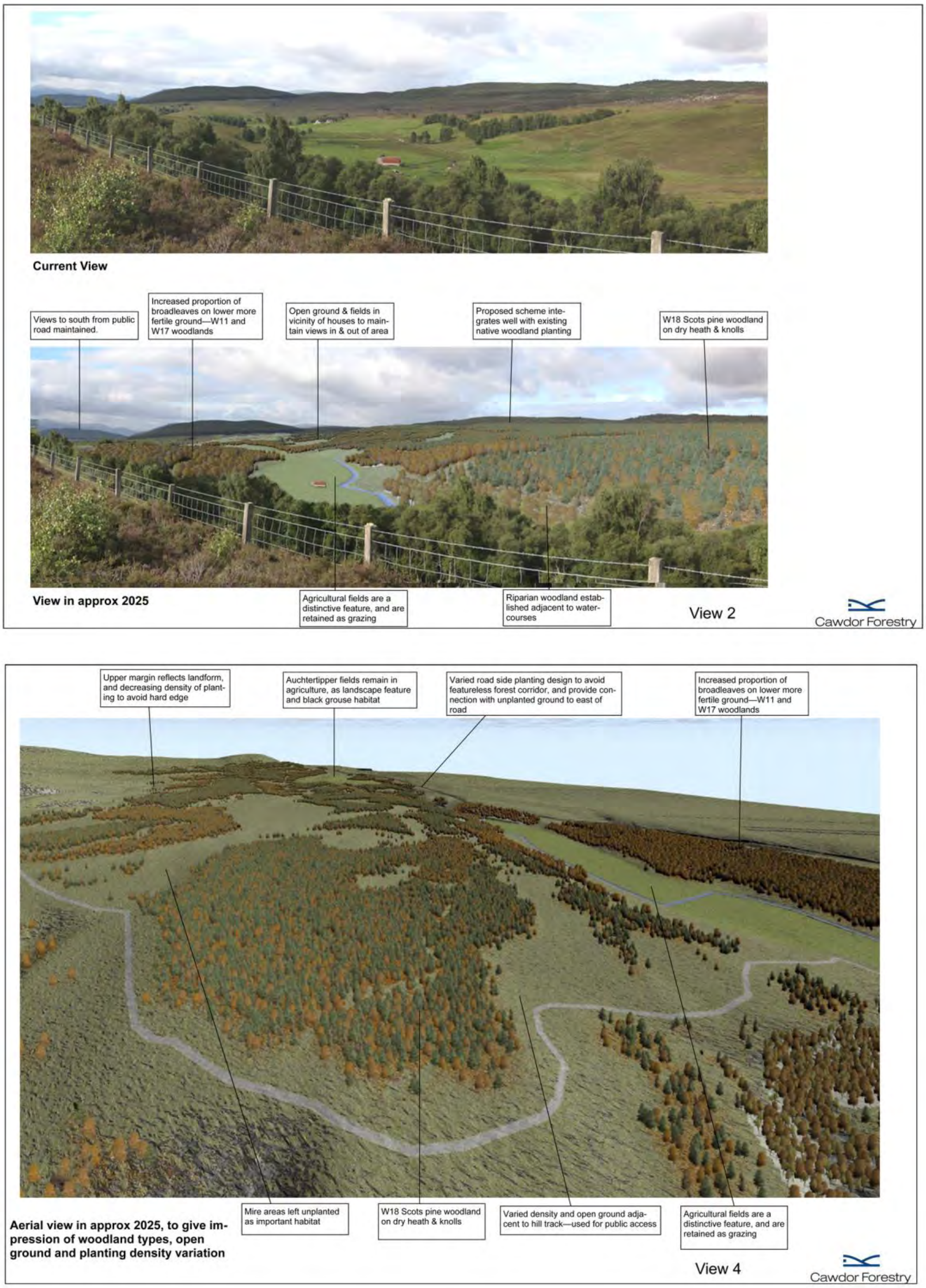
Similarities

- Precision agriculture and forestry are required for assessing yield potential and addressing variability within a landscape.
- The technologies can be used for managing the agricultural or forestry enterprise whilst minimising the impact on the natural environment.
- Precision forestry and agriculture provide a source of data that can be used for modelling the impact of variables on final yield which in turn can be used to find best management practices to improve yield.

Differences

- Forestry does not require the sub-meter accuracy that is strived for in arable agriculture.
- The data collection is required for a crop which takes over 25 years to mature, not one year as in agriculture.

- There are no set field boundaries in forestry and changes happen frequently; such as selective harvesting of timber or thinning sections of the woodland.
- Forestry requires remote management.
- GPS and GIS is required in forestry to maintain a record of all activities carried out including those carried out by contractors – whereas in agriculture a visual assessment of work carried out is possible.



Imagery modelling the impact of a new plantation within a landscape *(Source: Cawdor Forestry)*

APPENDIX 2.0

Case Study : SUNDOWN PASTORAL COMPANY
Precision farming for land management

Cattle grazing at Sundown Valley Farm

Sundown Valley Farm extends to approximately 20,000 ha and is located on the northern Table Lands of New South Wales, Australia. Sundown Valley Farm is one of 4 farms owned by Sundown Pastoral Company which farms over 40,000 ha in total with approximately 80,000 head of beef cattle each year, sending 1,000 head per week to their finishing yards.

Sundown Pastoral Company was founded by Neil Statham in 1964 and is still owned and run by the Stratham family. Matthew Monkman, the manager at Sundown Valley Farm, has been working with the University of New England looking at the range of PA technologies and their potential application in improving pasture utilisation and livestock management.

There has been considerable investment at Sundown Valley farm with AUS $15 million being spent on pasture restoration. All the paddocks are drought proofed with storage dams that feed troughs via underground pipes. The investment in infrastructure is considerable.

Geo-referenced species and ground cover pasture assessments being carried out at Sundown Valley Farm

Sundown Valley Farm paddock system

Sundown Pastoral Company investments in farm water infrastructure - troughs

Sundown Pastoral Company investments in farm water infrastructure - water dam

The farm participates in the pastures-from-space system which uses daily satellite imagery to measure pasture cover and predict pasture growth. The system can provide pasture growth rate maps and feed-on-offer rate maps for individual paddocks. Agronomists at Sundown Pastoral use the data to determine which paddocks will be rested and which will be grazed.

The data from pastures-from-space is also integrated with soil electro conductivity maps, soil nutrient maps, soil moisture sensors and ground truthed bio-mass data, together with GPS animal tracking and performance records, to develop a farm management decision support system that ensures better utilisation of grazing and the ability to address 'in field' variation.

Historic data from pastures-from-space is used to relate previous pasture growth rates to rainfall so that pasture growth can be predicted and used to plan livestock grazing.

Paddocks are divided into 40–45 ha blocks of pasture. Soil data, together with previous stocking rates, soil moisture and forage growth potential is used to establish annual fertiliser requirements. Where paddocks have been mapped for soil nutrients, variable rate applications can be carried out.

During my visit to Sundown we carried out geo-referenced species and ground cover pasture assessments which were going to be used against the pastures-from-space data for that week to identify paddock zones for site specific pasture reseeding. The data was also going to be used for variable rate manure spreading.

The author completing a species and ground cover survey

As livestock are unloaded when they first arrive at sundown, their ear tags are read automatically as they come through the race and that information is passed to the central livestock database for the company. After approximately 60 days they are sorted by weight into management groups of 250 head which rotate around 4-6 paddocks at pre-determined stocking densities which are assessed on the productive capability of the land and projected grass growth rates.

All livestock movements and husbandry tasks are recorded on their own central livestock management system which is easy to use, operated via a touch screen. The system is networked and updates immediately providing real time information for any other managers at Sundown Pastoral.

Other technologies currently being considered included GPS livestock tracking to provide further information on livestock location, movement and health. When dealing with such large livestock numbers tracking is important. They are currently testing walk-over weighing systems to automate the weighing process. Each group of 250 cattle are weighed 4-5 times during the 120 days they are on the holding, and the ability to weigh automatically when moving cattle between paddocks would be time saving and more efficient.

Sundown Valley farm was an excellent demonstration of the utilisation of precision agriculture technology for land management, which balanced the production needs of the cattle enterprise with the environment.

APPENDIX 3.0

CROP MODELLING : PETER KAYLOCK and IAN DELMENICO
Crop Rite PTY Ltd, Moulamein, New South Wales, Australia

Harvesting at Moulamein, New South Wales, Australia

Part of my travelling in Australia took me to Peter Kaylock, a 2013 Australian Nuffield Farming Scholar from Moulamein in New South Wales. Peter is the owner/manager of approximately 7,000 hectares producing, rice, dry land cereals, potatoes, stone fruit, fat lambs and cattle. Peter introduced me to his agronomist, Ian Delmenico of Crop-Rite PTY Ltd, to show me how he utilises precision farming technology to assist in the management recommendations for DD Kaylock and Co.

Ian had carried out an EM38 soil survey of the land, reading to two depths which he felt provided the most information. The EM38 readings were taken at 30m transects on the dry land and 15m transects on the irrigated land. The EM38 readings would highlight soil variability and only needed to be carried out once.

Calibration of EM38 sensors is a topical issue but Ian carried out base calibration by passing a specific marked point once every hour.

The EM38 readings provided a base to produce soil zone maps for management. In this case he produced three zones, but believed that the number of zones depends on the amount of variation and degree of variation within zones.

Soil sampling was carried out using a trailer-mounted sampler and the transects depended on the yield maps. All sample points were referenced using Trimble RTK GPS. Soil sampling is carried out every year.

The soil maps were used for variable rate applications of seed and nitrogen.

Average yields on the holding were 4t/acre for wheat and 2.5 t for winter barley. Within a normal growing season the average seasonal rainfall is 220mm. Much of the yield potential is related directly to water.

Each year Ian would produce a sowing report, which included variable rate seed maps and variable rate nitrogen maps. Ian utilised the grower-collected rainfall data to adjust recommendations for nitrogen and irrigation based on a detailed assessment of yield potential.

The breakdown of stubbles utilises Nitrogen when there is sufficient rainfall for its breakdown and this also had to be accounted for in Ian's model. NDVI data from remote sensing was used to monitor crop performance throughout the year.

Harvest yield assessments were recorded to validate Ian's model and an end of year report is produced as a form and set against Ian's other customers as a kind of benchmarking, and was used to consider how to improve water use efficiency. This is part of a 'plan to profit' vision that is promoted to farmers in Australia.

Ian was also using weed mapping to eradicate skeleton weed and other noxious weeds. All herbicide recommendations would be emailed through to the farmer's Agro apps.

Ian's model was based on the Opticrop model established by Philip Needham from the US. He has 18 clients within one region for his detailed agronomic service and he recognises that the current limitations on the utilisation of precision farming data is the labour required for interpretation of the data.

Yield potential monitoring has direct benefits in terms of managing risk. If the yield potential is low a decision can be taken about the inputs to be applied and potential cost savings.