



2004 SCHOLARSHIP REPORT
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Using Precision and Conservation Agriculture to improve farm profits and the environment.

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Executive Summary

Australian farmers are about to enter a new phase in increasing farm efficiencies which will not only help reduce their input costs with the same or higher outcomes, but will also help the environment.

In the past, nutrients have been added to our paddocks using the blanket approach, with nitrogen budgets being used to determine the rate for the whole paddock, but now with the use of GPS technologies there are new ways of bringing this budgeting into a sub-paddock level. At the same time there has been a renewal of interest in no-till and controlled traffic systems, which not only offer large improvements in farm logistic efficiencies, but also the productive base of our most valuable asset, our soil.

The purpose of my scholarship was to study Conservation and Precision Agriculture in different parts of the world that were adopting them, to assess their viability, and to see if they have a place in Australian Agriculture. The study also included going to regions of the world where very high levels of production are obtained, and bringing back information about where future increases in production are likely to come from.

My scholarship took me to many regions where agriculture has been practiced for a very long time, with large variations in soil types erosion levels caused by their farming practices. Also, with these regions having an ultimate aim of producing as many tonnes of grain as possible, to gain high levels of government subsidies, they have been over-fertilising their ground to ensure that nutrients are not limiting, which has caused large environmental damage to their waterways, with them having high amounts of Nitrates and Phosphates. Their governments have had to address this through new legislation, which restricts the amount of nutrients they are able to apply.

With the Australian environment being drier, and not having been under the influence of government production support, we do not have the same environmental problems, which gives us a significant advantage over other grain producing countries. We still need to be wary of pushing the boundaries in production, and still need to apply our nutrients in accordance to the expected yield, ie nutrient budgeting, for if we don't, public pressure might force us to do so, through government legislation. This is something that should be avoided at all costs for; it will place a burden upon our farming businesses.

I found on my study tour that Carbon farming is a vital part of conservation agriculture, having the potential to significantly improve our soils. This is done by placing carbon in our system, so our soils will be able to recycle the carbon into vital nutrients, as well as significantly improving the soil's structure and water holding capacity.

There are three aspects to Carbon Farming:

1. Moving into No-Till to stop destroying the carbon build-up in the soil.
2. Keeping all the crop residues to feed the micronutrients in the soil and provide carbon to the system.
3. Rotating crops to provide root disease breaks for maximum crop yield and providing high amounts of carbon containing residues to the system.

Complementary to Carbon farming we need to remove the compaction from our soils through the adoption of controlled traffic systems. This has become a lot easier in the last few years with the prices of Autosteer systems decreasing, allowing significant gains in farm logistics, and profits.

In the future Precision Agriculture will have a large role to play, not only in Australian Agriculture, but also worldwide. It has the potential to dramatically increase farm profits through placing inputs where the crop needs it, plus help the environment. There is a large range of new equipment that is coming onto the market which, when combined with existing Precision Agriculture techniques, will revolutionise agriculture worldwide. These include economical on-the-go sensors to map our soils, on-the-go grain analysers that will map the performance of not only yield, but also grain quality, new remote sensing equipment that will be able to recommend input rates according to how the crops canopy is looking at the time, but change the rate at the same time, and lots of other new tools that will benefit our production systems. There is going to be a lot of paddock data collected, and this is where specialist advisers will come into the system to analyse this data. It will take some time for these people to develop skills and grow their businesses large enough to be economical.

My report will cover all of this and more, and hopefully will contain information that will move agriculture forward regarding profits, and the preservation of the environment.

Acknowledgments

I would like to thank the Australian Nuffield Farming Scholars Association for giving me the opportunity of a lifetime in travelling the world studying my chosen topic, and a study of agriculture in the world in the global focus tour.

Thanks to my sponsors GRDC for giving me the opportunity to give something back to Australian agriculture, through your generous bursary.

Thanks to my Wife Nola for holding up things at home, looking after my sons Sam and William, and allowing me to undertake this study tour.

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Lastly, I would like to thank the 2004 Australian Nuffield Scholars for giving me the time of my life on the Global Focus Tour, and developing lifetime friendships, all the Nuffield Scholars worldwide for giving me excellent contacts, and hospitality, and the Scientists, Advisers and Farmers for passing on their valuable knowledge plus giving up their time to see me on my study tour.

Aims\Objectives\Study Goals

I have a passion for precision agriculture, conservation agriculture and other new cropping technologies, and the savings that they can provide farming businesses and the environment. I believed that an overseas study on these topics would enhance my knowledge and, with the extension I am already doing, help with the adoption of these technologies in Southern Australia.

Part of the reason these technologies are being adopted slowly is that the economics are unknown, so my visiting areas in the world where they are better defined would help me to understand the next level of adoption needed in my farm in Southern Australia.

Also, visiting regions of the world where the growing environment is better than in Southern Australia would give me an idea of where the next increase in yield is likely to come from, which also would include how these countries are managing their canopies for optimum yield.

While overseas I hoped to see how governments are addressing land degradation and the pollution of waterways from agricultural inputs, and as my study progressed the stronger this desire became.

Our group left Australia in February 2005 to attend the 2005 New Zealand International Nuffield Conference. This was a great start to the trip and gave the group lots of contacts and an introduction to being part of the Nuffield network. We then spent the next six weeks on the Global Focus Tour, looking at the “big picture” in Agriculture. We saw vertically integrated farms, spoke with farm unions and government policy makers, all of which gave us a great understanding as to where Australia fits into the world in terms of supplying food and fibre to the world’s population. It also gave us an insight into the political environment our policy makers must work within to get the best deal at an international level while protecting Australian agriculture from a suite of pests and diseases that are not currently found in Australia.

The tour included visits to New Zealand, California USA, Alberta Canada, Washington DC USA, Maryland/Virginia USA, England, France, and Brussels. The tour gave me a great insight into the environmental problems associated with agriculture, and how governments are dealing with them. This aspect formed a basis to my personal study.

Upon completion of the Global Focus Tour I spent three weeks touring the cropping regions of England before returning home to do my sowing.

Late in June I returned to Scotland with my wife who spent next three weeks touring with me. Together we travelled in Scotland, England, France, and Washington. After my wife returned home I completed my scholarship with five weeks visiting Chicago, Saskatchewan Canada, the Mid West of the United States, and finished my tour in California.

Introduction

All my farming life I have been fascinated with pushing the boundaries in farm production, and have developed complex rotations, used new fertilisers and chemical inputs to boost farm profitability and, you might say have, been an early adopter of new ideas.

In 1996, when Pivot came into the area promoting this system called Precision Agriculture, I thought, "I'll be in on that" and in 1997 purchased a yield monitor with my new harvester. With my first harvest with it I became very quickly aware of the variability of yield that was occurring on my farm. While much could be seen with the naked eye, a lot of variation is hidden in lack of grain numbers and size. This thought process started my quest as to what was driving this variability and why there were areas in my paddocks which were reasonable producers of straw, but very poor producers of grain.

The initial research using soil testing of high and low yielding areas failed to deliver answers to the variability. This left everyone confused and disillusioned. The support network around the yield monitor fell away after a couple of years and I was left, unsuccessfully doing my own research. In 2002 with the purchase of a new air-seeder I decided that the only way forward was to invest in new technology and purchased a KEE controller with Variable Rate Technology (VRT), and Global Positioning System (GPS) guidance. GPS was already being used with the yield monitor. However, the questions remained - How was I going to make this equipment pay, How am I going to make money out of the variability I was seeing in my paddocks?

In 2002 I variable-rate sowed a few paddocks, changing fertiliser and seeding rates according to what I considered were High and Low yielding areas, however this was all done on gut feeling, made me feel better, and proved that the technology worked. I did not know if, scientifically, it was the right thing to do, and still wanted to know more.

Also in 2002, when at a GRDC Adviser Update in Adelaide, I became aware of a small group of farmers and advisers from the Mid North of South Australia who were at the same stage of adoption. They were also disillusioned with the lack of support in Precision Agriculture they were getting. They were proposing, at the Update, that an association be formed to collaborate research and direction to move Precision Agriculture forward. I leapt at the opportunity to become involved, and, upon the

formation of this group, now named Southern Precision Agricultural Association (SPAA), was elected onto the committee, a position I still hold.

This group wanted to do research in South Australia and through GRDC's SIP09 project on Precision Agriculture put forward two paddocks for intensive research by the Australian Centre for Precision Agriculture, at Sydney University. This opened my eyes to up-to-date research and scouting tools, and has allowed for rapid adoption of the tools of Zonal Management on the rest of the farm. The question still remains: How are we to make money out of these zones?

Having heard many speakers talking about "Canopy Management" in crops over the years, I am of the belief that we should be able to do better in our cropping systems, for in high rainfall zones we are applying too much fertiliser early, maximising plant growth, and when the season finishes up, running out of water to fill the grains, hence high biomass crops are contributing to a reduction of yield. One could say that we are going over the top with our nitrogen inputs to produce this excess growth. Overseas research has shown that delaying application of the Nitrogen until the crop needs it is more efficient canopies for optimum yield are produced. Not only are they using Nitrogen timings to manipulate the canopy, they are also using plant hormone sprays called Plant Growth Regulators to shorten the crops height, strengthen the straw, and hence reduce lodging, for increases in yield. This is a topic that I have wanted to investigate further.

With the adoption of GPS guidance and the matching of all the in-season farm equipment to run on controlled traffic lines in 2002, I started sowing up and back, and the new sowing equipment allowed me to sow in a one pass operation called no-till. In 2005 we purchased a 2cm accurate RTK (Real Time Kinematic) auto-steer system to further enhance the controlled traffic system. These permanent wheel tracks have been placed on quite steep and variable slopes in odd shaped paddocks with contour banks and creek lines that had often been thought too difficult for controlled traffic. That year we also built a urea boom that fixes onto our Horwood Bagshaw air-seeder box, and this has been used to "variable rate" urea late in our cereal crops.

The land in which I farm is very exposed to soil erosion and the soil needs to be kept structurally sound for high production levels to be obtained in the long term. The development of the system I currently use has always aimed for long-term sustainability by protecting the soil and environment. The introduction of Precision Agriculture has had an underlying desire to put nutrients where they should go, for example, matching

crop inputs to crop outputs. Over the years, I have seen many environmental groups pointing the finger at farmers for problems in the ecosystem for off target nutrient waste from agricultural land, and feel that Precision Agriculture is a very important tool in addressing some of these problems.

In this report I will investigate what is being done worldwide about the economical use of precision and conservation agricultural techniques, and how these techniques stop some of the land degradation that is occurring from unsustainable agricultural practices.

1. The Farming Environment.

1.1 Where does yield variation come from?

The environment in which we farm is an ever-changing one. The land was formed through sedimentary deposits that have been uplifted, waterways forming the land. Rivers and creeks, and glacial cutting of the land have left the land we farm variable. We also have to work with many different soil types of different characteristics that result in different yield potentials. Some soils have very different water holding capacities, others extreme pH levels leading to nutrient tie-up, others have chemical makeup that restricts plant root growth like Sodicity and Salinity, and others have soil densities that restrict root growth.

Erosion

The agricultural lands in which we farm are eroding. We are accelerating it through our modern farming practices. Historical farming practices have left the soil bare at times, leading to water and wind erosion, and our cultivation practices have moved soil down the slopes of our hills into valleys below.

I could clearly see the effects of erosion when travelling in the air as part of my study tour, with the raised sections in fields being a different colour (mostly paler) than the valleys. This was extremely evident in Saskatchewan Canada and in some of the Mid West States of the United States, where erosion has left a very pale, highly alkaline layer on top of the rises and very rich soil on the bottom of the slopes. Jerry Hatfield of the National Soil Tilth Laboratory in Iowa, USA and Guy Lafond of Indian Head Research Centre in Canada both told me that this erosion has caused great yield variation in their two regions. Jerry also told me that it is quite common to see up to 200% difference in Water Use Efficiency within a single paddock in the United States.

Soil Type

When soil type changes across the paddocks there can be associated changes in soil texture which in turn leads to differing water holding capacity of the soil types, with higher clay content in the soil leading to more water being able to be stored. A clay soil will generally store more water for use by the crop, differing from a sandy soil, which is has poor water retaining properties. Associated with these soil type changes can be different depths of soil with A and B horizon depth changing. With these two very

important layers of soil holding the key in holding not only water, but also nutrients, very different yield potentials according to the soil types, can result.

The water holding capacity of soils are more important in drier regions of the world where water is the limiting factor affecting yield, and hence is extremely important to Australian agriculture where dryland farming dominates.

Elevation

The elevation, slope and aspect of the land also have an effect on yield, and it depends upon where you are, as to how it affected yield. The basic theory is that water flow off a slope leaves the hilltop with less water than the valleys below. It depends upon whether you are in a dry or wet environment as to whether it is positive to yield or detrimental to yield. This might change from season to season. Another effect on elevation is that low-lying areas are more prone to frosts and hence from time to time can be lower yielding. In areas of the world where they get snowfall the valleys collect snow, a vital source for water, and hence snow can be a benefit or detriment to the crop, depending on whether it is short or has an excess of water for the crop.

Slope

The slope has an equal effect because the steeper the slope the more chance that water will flow to the valley below, and infiltration of water on that slope will be poor. In the case of Irrigation, any slope will have an effect on water flow and retention. This was very evident in Californian Cotton, where they have areas that are not completely level showing very different Cotton yields.

Slope can increased the incidence of water erosion, with valuable A and B horizon soil being lost from the slope to the valley below, or even worse, lost from the paddock all together with the water carrying soil into streams and depositing it well away from the site being used by agriculture.

Aspect

Finally, the aspect of the site must be considered as sunlight facilitates photosynthesis while at the same time drying out the soil. This is evident in areas of low sunlight, with higher yields expected on the sunny side of the hill. In contrast, in areas of ample sunlight, the west facing slopes in South Australia is seen as the poorer yielding slopes, and the Northern slopes are seen as warmer. Yield reduction can occur from the exposure of the crop to hot prevailing winds at critical stages. This is evident on my farm.

When fertilizers such as Manures, Lime and Gypsum are carted to the paddock the tendency is to dump the piles close to the gate. Over time these areas become rich with fertilizer.

Rainfall patterns also lead to a variation in yield, with heavy isolated rainfall events such as thunderstorms favouring different parts of a single paddock. While not repeatable, this is a reason for differing yields.

Weeds are patchy in the paddocks and, in the case of the Australian problem of resistant ryegrass, can be very detrimental to yields.

1.2 Environmental problems caused by agriculture – the need to do better!

There is currently significant scientific consensus that human activities such as burning of fossil fuels, land clearing and inefficient land-use practices are increasing the concentration of greenhouse gases in the atmosphere in a process referred to as the enhanced greenhouse effect.

The greenhouse effect is a natural occurrence in which surface temperatures of the earth are regulated by gases such as water vapour (H₂O), carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) in the atmosphere. These gases act like a blanket trapping heat from the sun's energy that would otherwise be lost. Without this natural effect, the temperature of the Earth's surface would be well below freezing.

With increasing amounts of fertiliser being used throughout the world there is an increasing awareness of agricultural inputs leaving paddocks and finding their way into the atmosphere or into waterways, causing serious environmental problems. This is referred to as "non-point source pollution".

1.2.1 Carbon Dioxide (CO₂) Loss.

Carbon Dioxide (CO₂) is one of the major greenhouse gases. When the soil is tilled, carbon dioxide (CO₂) is released from the soil. Because of this, no-till groups throughout the world are investigating and establishing "carbon trading" systems that will allow them to offset carbon emissions from one activity with activities that will result in carbon sequestration.

1.2.2 Nitrous Oxide (N₂O) Loss.

Soil denitrification, the conversion of plant available nitrate to nitrogen gasses, which occurs under anaerobic soil conditions as a result of water logging, produces nitrous oxide (N₂O), another greenhouse pollutant. Nitrous oxide is also released by burning of fossil fuels and plant materials, and by the use of nitrogenous fertilisers in agriculture. It can stay in the air for more than a century. Although not as plentiful as CO₂, N₂O is more potent and therefore has more effect on the atmosphere by trapping radiant heat.

1.2.3 Nitrates (NO₃) and Phosphorus (P) Loss.

There is an increasing awareness throughout the world about Nitrates, Phosphates and Pesticides getting into waterways and this has prompted much discussion whether to ban certain chemicals or greatly restrict agricultural activities that would potentially impair water quality.

The leaching of nitrates into waterways can cause drinking water problems and at high levels can be a threat to human health.

Nitrates can also be transported to estuaries and bays by the river systems, and can cause a hypoxia zone. A hypoxia zone occurs when excess nitrates and phosphates from fertilisers, sewers, etc cause a flush of marine life (eutrophication) at the bottom of the marine food chain which, when they die, sink and photosynthesise a bloom of natural bacterial degradation exhausts the water's dissolved oxygen. The nett effect of this is a rapid kill of fish and shellfish in the estuary. In the United States this occurs in the Gulf of Mexico where the Mississippi river meets the sea, and the Chesapeake Bay area, South East of Washington DC.

According to the National Oceanographic and Atmospheric Administration, hypoxia occurs in more than 50% of the United States' estuaries. Worldwide there are 146 hypoxia zones, including sites in Europe, Japan, China, South America, and South-Eastern Australia.

In the Gulf of Mexico the problem seems to stem from the rich agricultural lands of the Mid West States including, Iowa, Illinois, Missouri and Arkansas where Nitrogen (N) and Phosphorus (P) are used in high amounts in agricultural fertilisers. Initially the blame was put on N only, but recent studies have indicated that P is an equal contributor. When manures are applied to the soil on the basis of crop N needs, then P is being applied above that which a crop will utilize, and over time this will lead to enrichment of

soil-P and increase the risk of non-point source contamination to surface waters. (Gulf of Mexico Alliance White Paper, 2005)

In Australia, Phosphates from agricultural land have been partly blamed for eutrophication in major waterways causing algal blooms, with the most famous one being the large blue-green algal bloom in the Darling-Barwon River in 1991. Research into this has show that much of the Phosphorus came from natural sources.

The Australian environment is mostly hot and dry, so doesn't have the same scale of problem of non-point source pollution coming from our agricultural lands compared with many northern hemisphere countries (Donnelly et al, 1998). With the large increase in fertiliser use in high rainfall cropping regions of Australia in recent years, care must be taken to ensure that we don't repeat the problems experienced by the high rainfall regions in northern hemisphere countries' also. If the global warming projections are correct, more extreme weather events will increase the risk of water erosion causing phosphorus movement from agricultural lands into our major waterways. This is considered as to be the main method of agricultural phosphorus movement into waterways (Donnelly et al, 1998).

1.2.4 Soil Erosion

Soil erosion is another large problem and is the main environmental problem on my farm in South Australia. Not only is it the loss of physical soil, but also the loss of vital nutrients and organic matter which has been built up over time for the future needs of the plants.

The main element of loss is phosphorus (P). When plants die, microbes decompose the plant residues, mineralizing the organic P converting it into inorganic forms. Inorganic P is very reactive, so it binds mostly to the smaller sized fraction of soil particles at or near the surface. Over time, this process causes an accumulation and enrichment of P at or near the surface. Application of P fertilizers and manures to the upper soil profile further adds to this. Surface water runoff then has the potential to transport large amounts of P to surface waters because it contacts a P rich zone and the smaller the particle fraction of the soil is eroded preferentially to the larger and heavier soil particles that have a lower P content.

In terms of total P, runoff erosion contributes the greatest amount of P to surface waters. In the past, P carried by soil water leaching to surface waters was considered to

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be insignificant. But lately soil testing has shown dissolved P concentrations in leached subsurface flow have occasionally been measured that are high enough to cause impairment of surface water quality from this fraction alone (Dinnes, 2004). When rainfall occurs at times of little or no plant cover and active growth, there is a greater chance for runoff and leaching losses of contaminants. Given that in Southern Australia we grow our crops over the winter months, our soils are at the greatest risk at the break of the season (the first major rains of the year) when no, or very little, plant material is available to stop water erosion, and hence the avocation of retention of stubble and cover crops to protect the surface from erosion.

Wind erosion occurs in the dryer regions of the world like Australia, and has the ability to move soil into the atmosphere, carrying organic material and nutrients with it. This occurs when the soil is dry and the ground is left with very little soil cover, strong winds sweep the ground and suck up particles into the air, either moving the particles into different regions of the paddocks or, in the case of very fine particles, very high into the atmosphere and be lost to the sea.

1.2.5 Tillage on Nutrient loss

Tillage is a destructive activity that can lead to non-point source nutrient pollution. Tillage increases aerobic microbial activity leading to elevated mineralisation of soil organic material (SOM) nitrogen (N). However, a dependence on tillage to release N for crop production is generally not a wise soil management practice, as it releases N at a time when the crop cannot fully make use of it, and therefore is more prone to leaching into the water table.

Tillage also breaks bonds between soil particles and aggregates. Subsequent rainfall events lead to crusting at the surface that greatly reduces the ability of water to infiltrate into the soil. The long-term effect of tillage causes reduced water infiltration, which, coupled with the burial of residue and exposure of loose surface soil particles. This leads to an increased risk of sediment erosion and non-point source P contamination of water resources.

Which type of P is at risk differs according to tillage regimes. The more intense the tillage practice, the more soil structure is destroyed, resulting in a greater amount of detachment and erosion of soil particles. Therefore, losses of P attached to soil particles are more common so-called conventional tillage practices. Reduced or no-till soil

management practices tend to cause a greater amount of P accumulation at the surface of the soil and a decreased potential for soil particle detachment compared to conventional tillage, but with the higher water infiltration in these systems the losses of P tend to occur through leaching of the dissolved P. This is considered a minor problem, especially in the dry Australian environments, and the greatest risk of P loss is under the intense tillage system (Dinnes, 2004).

Another destructive factor that can vary proportionally with tillage intensity is compaction. Compaction also affects nutrient losses. When soil is compacted by tillage, vehicles or livestock, bulk density increases and water infiltration rates and water storage potential decline. This will cause increased runoff erosion of sediments and risk of non-point source P losses to surface waters. In addition, crop yields are less under compacted soils through restricted root growth, so there is less chance for N and P uptake by the crop, leaving more left over for non-point source losses.

1.2.6 Pesticide Loss

There have been many cases in which pesticides are lost from agricultural lands through erosion and leaching into nearby waterways and lakes. This has led to the restriction of some pesticides and the banning of others.

1.3 Environmental Problems caused by Agriculture – The Economics.

There are economic losses associated with nutrients and pesticides moving from our paddocks to the surrounding environment. If these inputs are oversupplied to the farming system there is the immediate loss of profit from the agricultural enterprise. Bill Raun from the Oklahoma State University has calculated that the Nitrogen Use Efficiency (NFU) for cereal production in the world is 33%. If NFU were to be increased by 20%, then the world would save an estimated US\$6.9 billion annually. Bill says that 50% NEU should be achievable by better application techniques without compromising yields.

The effect of compaction also has a dramatic effect on farm profits because compaction decreases the farmable volume of the soil profile. Over time this compaction can lead to the reduction in volume of soil from which crop roots are able to extract water and nutrients by 1/3 or more (Dinnes, 2004).

1.4 Environmental Problems caused by Agriculture – The role of Government.

Governments throughout the world are addressing the problems of the oversupply of nutrients and chemicals in different ways.

In the UK they have Nitrate Vulnerable Zones (NVZ's), which cover most of the farmed areas in the UK. In these zones farmers are required to keep detailed records of fertiliser and chemical inputs, to show that they have not over-applied these beyond that required growing the crop. Restrictions on the amount and timing of applying manures to their land have also been introduced. For example, farmers can only apply 170kg/ha of manure on their arable land and this must be done in the months between August and November. Any application outside of this timeframe must have written permission approved at least 5 days prior to expected application.

When talking to farmers in England about this they stated that the bar had been set too high for them to worry about, but it did focus attention on more efficient use of their inputs. In contrast, farmers in Scotland are very aware of the restrictions and expect that the next round of laws will force them to think about restricting their inputs, or to apply the inputs where they will get the most benefits.

In France the farmers have avoided taxes on their fertiliser inputs, but in return they must do compulsory budgeting of fertiliser inputs.

In Denmark there have been taxes on fertiliser and chemical inputs for some time, reducing fertiliser inputs by 50%, but not without some economic loss. The average grain protein from the 1980's to 2003 has dropped from 12% to 9%.

When the group visited Brussels, where the European Union headquarters is located, we heard a presentation by Maeve Whyte of the UK National Farmers Union about a piece of legislation that will change the way European farmers will fertilise their paddocks in the future.

In 2000 a new piece of legislation called the Water Frame Directive (WFU) came into being. The aim of this directive is to raise the standard of water quality and prevent further deterioration in quality across all waters and wetlands. The outcome of this directive is that all water bodies in Europe will have to have to return to their natural state by the year 2015. This will mean considerable change to the way European

farmers use fertilisers and chemicals, and the way they farm in Europe. It is why all this new legislation is being set in European countries, and will probably have to tighten further if the new directive goals are to be met.

In the United States the farmers have to produce, and adhere to, a Nutrient Management Plan (NMP). Virginia and the neighbouring Maryland States are very concerned about the pollution that is entering their waterways. Denise Doetzer from United States Department of Agriculture (USDA) Environmental Department states that there are significant pressures for them to address their water pollution problem. This is evident in the Chesapeake Bay area where hypoxia zones have killed fish and shellfish vital to the economy of the Bay region. The farmers in this area must complete do a nutrient management plan (NMP) and strictly adhere to it.

The main problem seems to be that with a large, intensive animal industry in the area, farmers close to these areas have been applying too much manure on the land resulting in extreme Phosphorus levels, with the excess leaching or running off the land into the waterways. These intensive animal industries have to address this problem, and under the NMP's, are having to cart their manure further away at an increasing price, which is putting pressure on their businesses.

The Government authorities are placing all of the blame on the agriculture sector, but with increasing urban development it is likely that the excess fertilising of lawns that is going down drains and out to the waterways is also a major contributor. The government authorities are not willing to address this problem. The NMP's seem to be working at decreasing the amount of agricultural runoff, and the use of Precision Agricultural technologies is being done on an economic basis, not because they are being forced into it.

This situation is echoed in the Mid West states of the United States, where farmers are adhering to NMP's to stop the problem in the Mississippi river system.

In California farmers are also required to implement NMP's that address a problem of too much Selenium in their water. This causes Shore Line birds to produce very weak eggshells, and hence having a reproduction problem. When water is being moved from one paddock to another it must be tested and meet strict quality requirements, otherwise it needs to be treated. The Westland Water District and Bosewell Cotton farm have put land aside for the development of habitat for the birds so the birds can breed.

This has helped to redirect public perception as the farms are helping support an endangered species,

In Canada, in the province of Ontario, farmers must do an NMP by legislation, while in Quebec farmers have to do an agro-environmental fertilisation plan that is a form of NMP. Their federal government has a policy goal of reducing water contamination by nutrients, pathogens and pesticides, so there is pressure on all provinces to address potential problems (Fairchild, 2003).

In New Zealand pressure is coming on farmers because of excess nitrate levels in some areas and waterways, especially the Lake Taupo region in the North Island. Most of the blame seems to be directed at the dairy industry. It is accepted by the authorities that fertilizer itself is not the issue for it takes 80 years for the water to leak from the dairy land into the lake and nitrogenous fertilizers have only been used for the past 20 years, but the fact that it allows for high carrying stocking rates has caused farmers to limit fertiliser application in that catchment, but there is still argument as to how much this limit should be. Nutrient budgets are being promoted as a way of demonstrating best use, with some regional councils making them law, and some markets are using them to demonstrate best practice. There is talk that all farmers will be required to perform nutrient budgets by the year 2007. Community pressure on the Dairy Accord part of Fonterra's supply agreement has seen farmers fencing off waterways to reduce faecal contamination, and some regional council are seeking to extend it across all farming types.

With many of the world governments subsidising their farmers' incomes, they are influencing farmers through their policies, causing their farmers to push the boundaries of production in order for them to get maximum government payments. In Europe they have been down the path, since the 2nd World War, of putting subsidies on production. This has forced their farmers to apply very high rates of fertiliser to achieve maximum yields. Now they have to address with this through very strong nutrient policies which some countries are addressing adequately and others not. The uncoupling of payments in the UK from production is helping address this problem through lower yield targets, and hence fertiliser usage, might end up being more profitable than the high target yields they are aiming for now. This, coupled with the cross compliance subsidies they are getting for their environmental work, is helping them achieve their goals in cleaning up their waterways.

In the USA on the other hand, farmers get some of their subsidies through an insurance scheme, which guarantees a base income (i.e. they have an safety net). This allows farmers to focus on maximising production without the fear of having a bad income year, meaning that they are fertilising their crops accordingly, thereby reducing over-fertilization in some years, adding to their environmental problems.

2. Modern Farming Techniques to help the Environment.

I do not profess to have all the answers on the world's agricultural problems, but will discuss two major steps forward in improving the sustainability of agriculture in the cropping regions of the world, the first being "Carbon Farming" and the second being "Balancing Nutrient Availability to the Crop Needs".

2.1 Carbon Farming.

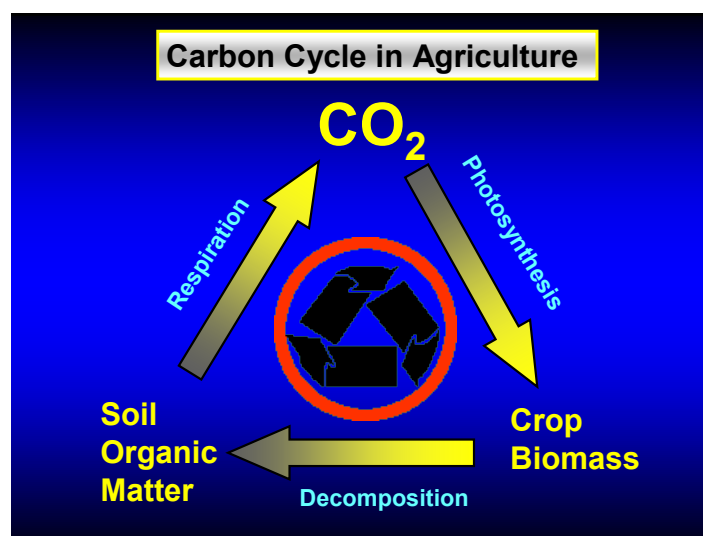
According to Dr Don Reicosky of the North Central Soil Conservation Research Laboratory in Morris, Minnesota, USA, there are three pillars to Conservation Agriculture.

They are:

1. Minimum Soil Tillage.
2. Crop Rotations/Cover crops.
3. Continuous Residual Cover.

All of these three pillars are related to SOIL ORGANIC CARBON.

When you look at Soil Organic Carbon you have to investigate the Carbon Cycle in Agriculture.



(Reicosky, 2005)

Figure 1. The Carbon Cycle in Agriculture.

Soil Organic Matter is a mixture of residual plant material in various stages of decomposition and microbial biomass and all of their by-products.

The “KEY” component is: CARBON!

Incorporating crop residues with intensive tillage it maximises residue-soil contact and is the fastest way to convert Soil Organic Matter to a “puff” of carbon dioxide. Crop residue decomposition cycle is a temporal continuum with carbon changing form and functions as CO₂ is released through microbial respiration. The less tillage we give the soil the less CO₂ is lost from the soil and therefore the less CARBON is returned to the soil for future BASIC ELEMENTS (Reicosky, 2005).

Jill Clapperton from the Rhizosphere Ecology Research Group in Lethbridge, Canada, was very quick in pointing out to the touring group that the soil was a living medium. Earthworms, insects and rodents are the most visible components of the “living soil” team. They work in tandem with soil microorganisms and fungi to contribute to aeration and nutrient cycling as part of a “soil factory” team effort. This activity occurs mostly in the top 20 to 30 cm of soil. She said “feed them and they will come”, which means that we must continue to feed these organisms with carbon for the cycle to continue.

The Mycorrhizal fungi present in the soil are great for nutrient collection to plants because this fungi forms a symbiotic relationship with the root system of the crop, delivering nutrients like Phosphorus, Calcium, Zinc, and Copper. It also aids in the transport of water and, in return gets direct access to the carbon rich products of photosynthesis. There are other beneficial fungi that live in the soil, as well as destructive fungi like Rhizoctonia. The secret is to keep the soil fungi in balance.

High earthworm population is considered to be very favourable to the rhizosphere because they increase soil aeration, water infiltration, nitrogen availability to plants, and the microbial activity of the soil. Earthworms not only provide tunnels that assist ease of root growth and water infiltration, but it has been found that these tunnels have higher concentrations of nitrifying bacteria than the soil outside the tunnel, thus encouraging root growth in the tunnel. Earthworms feed off the decaying plant material, fungi, protozoa and bacteria leaving behind sticky secretions, which bind small soil particles together into larger aggregates, improving soil structure. (West, 2003) The more diverse the “living soil” team, the more flexible the soil. This means the soil has an ability to grow numerous crops, under drought conditions and low nutrient conditions.

Intensive tillage destroys the biological and ecological integrity of the soil system, undoing all of the good described in the paragraphs above. Tillage very effectively facilitates biochemical degradation of Organic Matter, and it is this Organic Matter, which is the reserve of nutrients that will become available to future crops.

According to Don Reicousky of the North Central Soil Conservation Research Laboratory at Morris, Minnesota USA, we need a balanced nutrient status in the soil for both crop uptake and carbon sequestration.

Reiterating the opening statement in this section, we must enhance the amount of carbon that we have in our soils for the betterment of our soils.

We must:

- 1. Move into no-tillage to stop destroying the carbon build-up in the soil.**
- 2. Keep all our crop residues to feed the micronutrients in the soil and provide carbon to the system.**
- 3. Rotate crops to provide root disease breaks for maximum crop yield and providing high amounts of carbon containing residues to the system.**

2.1.1 Case Study 1. – Dakota Lakes Research Farm

Dr Dwayne Beck, Manager of the Dakota Lakes Research farm in South Dakota USA, backs up this research on his research farm and very strongly advocates growing as many high carbon producing crops as possible in the rotation as well as other carbon conservation methods. He is getting incredible results using this methodology.

The system that Dwayne has developed for his farm is as follows: -

- The crop rotation needs to reflect having the ability to sow early spring into heavy stubbles because the soils on the farm are difficult to sow when they are wet.
- He uses a very low disturbance disk seeder to allow as much carbon sequestration as possible.
- Because of the disk seeder he is harvesting wheat with a stripper front, leaving the straw attached and long to stop the problem of pinning of the straw.
- In the dryland part of the farm, his theory is to have two years of high carbon producing crops in three, with a grain legume to be used in the third year. He is attempting to go winter wheat – corn – field peas on one part of the farm, and spring wheat – winter wheat – field peas – corn – corn – peas on the other.

After 12 years the results have been staggering, with large increases in wheat yields, the high carbon rotation plots stood out with the high carbon rotation plots in very good condition, and the low carbon rotation plots showing severe water stress. A low carbon rotation would consist of one year a high carbon crop followed by a low carbon crop, ie wheat – peas – corn – canola. While a lot of these yield differences can be attributed to better catchment of water in the high carbon rotation, there is definitely an impact from the soil being in better condition to give up the water, to the extent that in years where water is limited, the yields in the high carbon rotation were significantly higher dependant of the crops grown.

When looking at the high carbon irrigated corn we could see excellent stubble cover and the earthworms were very active, and the water escaped out of the topsoil very quickly straight after a large irrigation.

It should be noted that his theories are based on observation over a 15 year period, and to date do not have scientific proof, but after being there and seeing the rotations under water stress, I have no doubt that his theories hold merit. With Australian wheat being grown under more moisture stress than in South Dakota, his practices and theories should have a large place here.

2.1.2 Case Study 2 - The effects on soil quality, nutrient availability under a long-term no-till soil. – Jim Halford's Farm

On Jim Halford's farm, just outside of Indian Head, Saskatchewan Canada, there has been a very interesting comparative study undertaken between a field under no-till for 25 years and a field just alongside which has been farmed using a wheat fallow rotation until 2001 when Jim took it under his no-till system. The results of this study have supplied researchers with the unique opportunity to compare the effects of long-term no-till on soil quality and nutrient availability with a conventional till system, and the change of the soil when adopting a no-till system.

The results of this study so far have indicated that adopting a no-till system will significantly increase organic carbon levels, water infiltration, porosity, soil moisture retention, and drainage in the field. Of particular interest was a large difference in the amount of nitrogen mineralised between the long-term and short-term no-till fields, with the long-term field being close to the native prairie values. It would appear that the observed increase in organic matter is having a major and positive effect on the availability and cycling of nitrogen. This was observed at the start of the study where the

yield and protein were measured in spring wheat crops, with significant and positive increases in yield and protein under the no-till system. Of particular interest was the fact that the grain protein levels were higher where no nitrogen was applied on the long-term no-till field than where 120kg/ha of nitrogen was applied on the short-term no-till field (Lafond et al 2004).

Table 1. The effects of length of no-till on grain yield (bus/acre) and grain protein (%) of spring wheat as a function of different rates of nitrogen at Indian Head, Saskatchewan, Canada 2002.

Nitrogen Rate (kg/ha)	Yield		Protein	
	LT	ST	LT	ST
0	42.6	26.2	13.3	10.9
30	44.8	32.9	13.7	11
60	49.1	40.2	14	11.6
90	51.5	47.9	14.2	12.3
120	49.8	47.7	14.4	13.1
	LT = 22 years no-till ST = 1 year no-till			

There are Phosphorus studies being done also, with an early indication that there seems to be a greater depth of phosphorus under the long-term no-till plots, giving a conclusion that mineralised phosphorus may be greater under this system. But Dr Jeff Schoenau suggests that even though this process occurs, it would not be enough to overcome the amount of phosphorus taken off in grain.

2.2 Balancing Nutrients.

Balancing nutrients to the crops needs sounds like a simple idea, but in reality it is not, particularly for Nitrogen (N).

2.2.1 Nitrogen

With Nitrogen, the challenge is to manipulate N availability to' during, and after peak crop demand so as not to cause either nett economic losses from yield reduction or N losses to the environment. Being able to optimise nett income and water quality is not just a matter of matching N fertilizer rates with crop demand, but is also a matter of timing of application. The risk of N losses increases as the time between N application and crop uptake increases. Also, applications of N should be accompanied with a rainfall event when spreading in season, to wash the nitrogen into the soil, and prevent it dissolving into the gas form of Nitrogen, NH_3^+ . When left on top of alkaline soils for extended periods, NH_3^+ is lost to the atmosphere through the process called Volatilisation. In essence, improving the timing of nutrient application and matching the amount that is available with crop demand can improve yield and quality.

Changing from applying all N at sowing to split N application systems (some at sowing and the remainder during the growing season) will better schedule N availability with crop demand. Plus it allows for in-season adjustment depending on how the season is going.

Also, changing the farming system into a no-till environment changes the amount of N available through the mineralisation process, and needs to be monitored through soil testing at the start of the year. During the year, a model of mineralisation N, which should be developed using tillage practice, rainfall and temperature, should be used to work out the amount of mineralized N available to the crop during the year. This portion of N in the nitrogen budget varies wildly from year to year, paddock to paddock, zone to zone within the paddock and hence, although it is very important in the budget, it is very difficult to predict.

Everyone whom I spoke to about predicting the amount of mineralised N said that this was very difficult to do, and Jerry Hatfield has it as his number one challenge to improving nitrogen management, in his paper "Agriculture and water quality – A National Perspective".

When I was at the National Soil Tilth Laboratory in Iowa I attended a seminar by Dean A. Martens "Fertiliser Nitrogen Use Efficiency – Practicality of increasing NFU?" where he was trying to work out why, when the rate of nitrogen goes up, the NUE decreases. His answer to this is that when nitrogen is applied, the nitrogen fertiliser is leached out of the system very quickly, but the fertiliser tends to stimulate the mineralisation process

called “Priming”. The more nitrogen fertiliser that is put on, the more total nitrogen is mineralized, but at a decreasing rate, and hence the NFU goes down. When fertiliser nitrogen is added to the soil, it does not stay as a single separate N pool, but very rapidly becomes mixed with the soil indigenous N pool via mineralization or immobilization. See the chart on the next page.

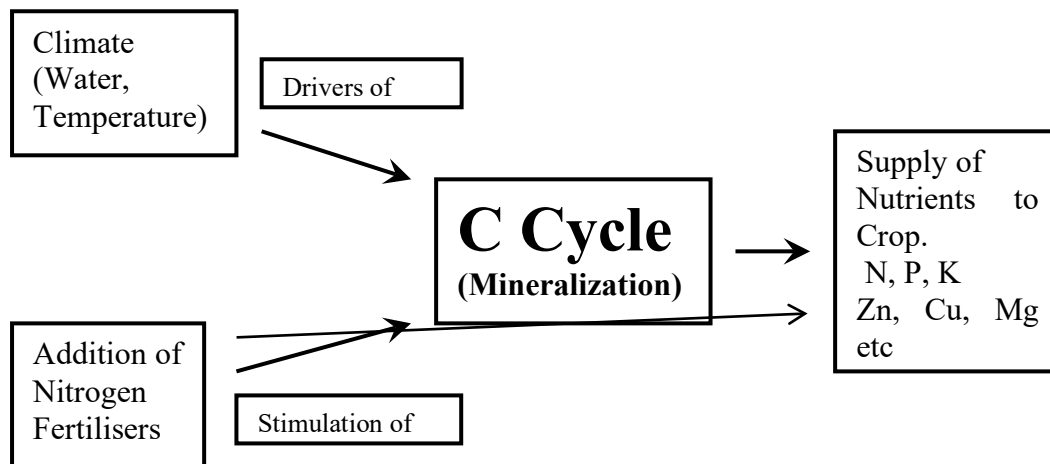


Figure 2. The effect of adding Nitrogen to the Carbon Cycle in supplying vital nutrients to a crop.

With the temporal and special variability of carbon in the paddocks, the amount of stimulation of mineralization from the nitrogen varies greatly, making the prediction of mineralization even harder. The climate has a large role to play, as for the bugs to be active need moisture, and the warmer the soils, the faster the mineralization process takes place, and hence there is a need for more accurate weather forecasting.

Western Ag. Innovations Inc. from Saskatoon Canada, have developed a system of probing the soil to test what nutrients would be available to the plant in a 24 hour period, and hence what nitrogen is coming from the soil at that particular time.

They have done this by developing a plant root simulation probe (PRS), which uses a membrane, which attracts either anions or cations, to the membrane. This simulates what root membranes do when bringing nutrients to the root, and so the probe is able to capture what nutrients would go into the root. Once captured the anions, or cations, are washed off and sorted out using a autoanalyzer, showing how much N, P K and S would have been up taken into the root.

A model has been developed by the company, which forecasts yield potential and demand. This model has the aim of optimising profit from fertiliser inputs using the PRS technology.

The model takes into account the total available moisture, growing degree-days to set the yield potential, and water storage, soil density, soil pH, and soil EC, which are attributes that can limit yield potential. Once the yield potential is set the probes are used to tell what nutrients are available in the soil for the plant to uptake. The nutrients needed to grow the yield potential, minus nutrients available to the plant in the soil, equals the nutrients needed to be added onto the field to reach the potential yield.

Given that the probes can be put into different parts of a field plus other precision agricultural techniques quantifying soil constraints, a variable rate map can be produced which can optimise the fertiliser rates for the field and hence the profit for the field. The farmers can do some adjustments in the model, which allows them to put in their own risk profile, and thus adjust according to how the farmer perceives the future of the crop.

Early work done on soil testing for Nitrogen by Bill Raun and his team at Oklahoma state university showed that in order for Nitrogen to be successfully variable rate applied from a soil test of organic carbon, and total nitrogen, the grid had to be at least 0.4M-2 or smaller, which clearly is not practical.

In the lecture by Dean Martins he also discussed the need for farmers to talk about optimum use of fertilisers, not just “brag” about the highest yield they achieved through using less optimal high rates of fertiliser.

New technologies based on Chlorophyll monitoring and Remote Sensing in conjunction with top dressing N show great promise and form a large part of my report, but have difficulty in defining proper N rates. This technology can also be used in attempting to work out the amount of nitrogen coming from the soil, by comparing a nitrogen rich strip with the paddock average, using a Greenseeker ® sensor.

One method of working out variable rates of Nitrogen in a paddock is to create Nitrogen Management Zones by using historical data of total N removal in a paddock, taking off the N deficit of the last crop, and by adding the removal and deficit together to give a rate of Nitrogen required for a future crop. To accurately work out the amount of Nitrogen removed from the paddock, there needs to be a calculation of not only yield, but also protein. Yield maps can give yield variation across the paddock, but we need to

do the same with protein. The problem to date has been the unreliability of on the go Protein sensors, but with the release of Zeltex “AccuHarvest On-Combine Grain Analyser” further research into this method will have to be done to show it’s value. The Zeltex “AccuHarvest On-Combine Grain Analyser” will be discussed later in my report.

2.2.2 Phosphorus and Potassium.

Phosphorus (P), and Potassium (K) are easier elements to predict the usage of because of their stability in the soil, and in the case for Phosphorus, there are numerous models available that provide P recommendations. The models use soil tests, soil types, crop type, and expected yield.

In the past farmers throughout the world have used a blanket approach to P according to yield expectations, and have been building phosphorus in different rates in the paddocks, because of the yield variation across the paddock removing different rates of P. This has left phosphorus across the paddocks at very different levels.

With the initial move to address this, farmers in Europe and the United States started a campaign of grid sampling. But over time this was proven to be too expensive, and there were only two companies in the world that were advocating it. These companies are SOYL, which is the biggest precision agriculture company in the UK, and Opti-Crop in the United States. Both are using 1ha grids for measurement of P, K, and pH. The problem with this is that statistically this would give a very poor result, given that spatially there is not enough data.

I discussed this with SOYL in detail and they agree that it might not be statistically ideal, but were adamant that it was providing maps that were able to give the farmer with enough variation that they could make good profits from variable rates of nutrient being used. I saw numerous financial analyses that backed their claim, and they were very impressive. Over 151 farms they claim an average of \$A13.4/ac/year, with the average system costing \$A6.5/ac/year. This was for the whole grid-sampling package, with P being a major component of this. Over time they have shown that this method has evened up the P, K and Mg in fields that have been using it for 10 years, with more of these nutrient samples falling in the optimum range.

When talking to Chris Dawson who is the Secretary of the International Fertiliser Association and head of the Precision Farming Alliance in the UK, he suggested that in order for grid sampling to work in P and K, the grid size would have to be no larger than

40 square metres, and a better method would be for P and K to be put on at replacement rates from the previous years' yield maps.

Jim Wilson of Soilessentials in Angus, Scotland, has taken this a step further and has created zones off previous yield maps on the P and K lost through grain being exported. He has soil tested the zones, and created rates by replacing and correcting to bring his paddocks back to being even again. This method may not be applicable in Australia for it does not take into account the in-field variation, with higher rates of P needed in high yielding zones, than in the low yielding zones for optimum fertiliser usage.

Personally, I think that there should be a blending between the two methods. If Jim's method is used, and use the high and low yielding zones to set different targets, and then use the yield maps to replace the exporting P (and K, if K is a limiting nutrient) at equal to the replacement if P and K are at adequate levels for the zone, higher than replacement if P and K needs building, and lower than replacement if P and K are in ample supply. Constant geo-referenced soil tests would have to be done to see how this is affecting P and K levels, and to track any changes in mineralized P and K that are coming into the system, such as the change into no-till, which over a long time lag will increase the amounts of mineralized P and K.

This approach can also be used in correcting any trace element deficiencies that might occur from differing soil types.

In areas of the world where farmers have access to animal manures, and where they have been applying the manure for the nitrogen component and forgetting about the equally available phosphorus, potassium, and trace elements, levels of these elements are very high and it is highly recommended that fertilising with these elements be stopped, or at least greatly reduced, in order to mine the excess nutrients, and stop them eroding or leaching onto the world's waterways. This leaching is considered by a lot of people throughout the world to be the biggest problem in non-point source pollution.

2.3 Correcting Soils Problems.

The soil is a medium for the crops to gather nutrients, and water for maximum yield. If the soil's properties are not ideal then maximum yield cannot be obtained. It is up to the individual farmer to work out the economics of identifying and correcting some of these soil problems, which in some cases might be occurring in patches across the paddocks, and hence precision agriculture helps in the identification, and by operating in patches helps the economics of correcting these problems.

2.3.1 pH

Soils can be naturally acid or alkaline, and this can be measured by testing the pH value of the soil. Having the correct pH is very important for healthy plant growth, as it affects the amount of nutrients that are soluble in soil water, and therefore, the amount of nutrient available to plants.

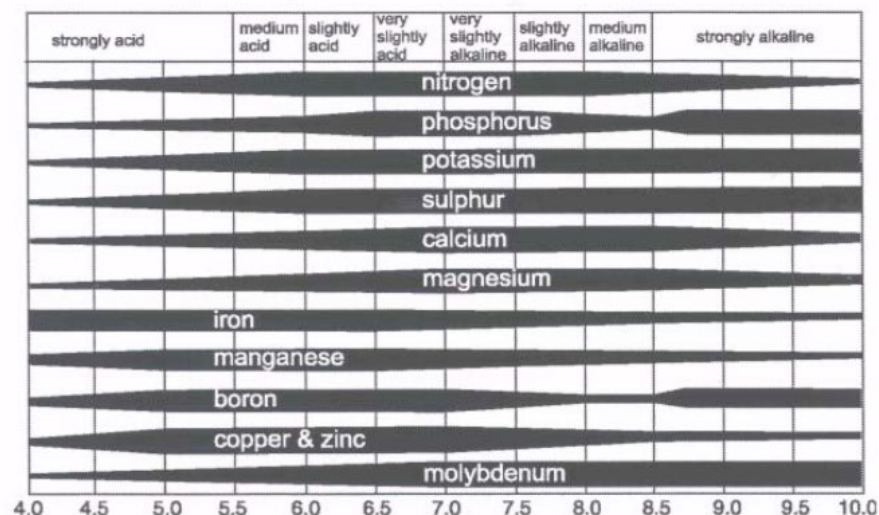


Figure 3. Effect of pH on Nutrient Availability.

Some nutrients are more available under acidic conditions while others are more available under alkaline conditions. However, most mineral nutrients are readily available to plants when soil pH is near neutral. If the soil is strongly acidic (pH less than 5.5), or becomes so, this can result into poor plant growth through one or more of the following factors: low pH, aluminium toxicity, manganese toxicity, and low levels of essential plant nutrients such as phosphorus and molybdenum. Alkaline soils may have problems with deficiencies of nutrients such as zinc, copper, boron, and manganese. Soils with an extremely alkaline pH (greater than 9) are likely to have high levels of sodium.

The correct balance of trace elements is obtained where the soil pH is between 5.5 and 7.5, so every effort should be taken to check soil pH levels regularly. Early identification of soil pH problems is important, as it can be both costly and difficult to correct long-term nutrient deficiencies.

Some fertilisers can change soil pH and thus cause other nutrients to be more available to plants or, perhaps, reduce their availability. Some nitrogen fertilisers, and the use of legume crops and pastures have the ability to reduce pH and make the soil more acidic, and hence in areas where intensive agriculture are practiced, we need to watch that we

are not acidifying soils too much and so causing problems in those soils. When soils are too acidic for a particular crop, lime or dolomite can be used to increase the pH to the desired level. The amount of lime or dolomite required to correct an acidic pH will vary from soil to soil. Soils with high organic matter and clay content will be more resistant to changes in pH and will require higher application rates. Therefore, soil pH, while indicating the need for lime is not a reliable guide as to how much lime is required, and the farmer should contact local advisers regarding how much lime will be required to correct a problem.

In Australia it is estimated that there are 33 million hectares of farming land with a pH of less than 4.8, and hence there is the need for large amounts of lime to be spread across paddocks to correct these acidic paddocks.

The most common way of identifying whether there is an acidic problem comes from a standard soil test, with a recommended rate being attached if the test deems that some correction is needed. With the variation of the soils across the paddocks, in areas where acidity is a problem, this problem tends to vary across the paddock as well, and hence a blanket application of lime is not the most economical method of applying lime, but it can also cause pH problems of its own with over and under correction of the problem, causing poor growth of the crop through pH falling outside of the desired level.

In the early days of precision agriculture, many areas of the world went down the path of addressing this problem by grid sampling pH, along with P, K and Mg, and applying different lime rates according to the grid they have developed. For research purposes this was fine with very good maps being produced at a grid that was very close, but when you took it to the commercial stage, to make the service economical the grids had to be adjusted out to 1ha grids. Chris Dawson of Chris Dawson and Associates believes that 1ha grid sampling is too far apart to produce a map that is statistically relevant and the furthest apart should be 40 square metres, but this is too expensive.

The only existing business that seems to be economical at close to this rate is Jim Wilson's "Soilessentials" business out of Scotland. He is sampling on 50 square metre grids for pH costing A\$30 for 4 samples/ha, which includes map production and recommendations. A sample comprises of 10 to 16 sub-samples from a 30-metre radius; this sub-sample is bulked, mixed and then re-sampled to get the final sample for analysis. Accurate sampling is vital, for the aim is to get the average pH for that grid. He tends not to produce contoured maps, as he believes they introduce another error into

the process, but simply enters the pH value into each grid, assigns a lime rate based on that value, and then spreads on that grid. That way the amount of lime spread is directly related to the average pH of that grid and no interpolation errors are introduced into the application map. It must be noted that yields in Scotland are very high, and their soils vary considerably across their paddocks.

Other grid sampling businesses I came across were SOYL, the largest precision agricultural company in the UK, and Opti-Crop from Kentucky USA. Both companies are using 1 ha grids, and SOYL agree that 1ha grids are not statistically ideal, but were adamant that the service was providing very good returns to its growers, and after seeing figures from James Price, a farmer in Oxford England and the company itself, I would have to agree with them. With SOYL also testing and correcting for P, K, and Mg, over 151 farms they claim an average of A\$33/ha/year savings, with the average system costing A\$16/ha/year.

An improved method of sampling pH has been the development of mobile pH sensor platforms, which when added to GPS equipment can sample at a much greater and more economical rate, producing maps that are accurate and affordable. The two commercial platforms that I came across were the Veris pH Manager, from USA and the yet to be named, on-the-go Soil pH and Lime Requirement Measurement System (SpHLRMS) developed by the Australian Centre for Precision Agriculture, the Swedish Institute for Agricultural and Environmental Engineering, and Computronics Holdings Limited from Perth, Australia. Both of these systems will be reviewed later in my report.

2.3.2 Sodicity

Sodic soils are harmful to plants principally because it induces undesirable physical and chemical conditions in soils. A sodic soil is defined as soil that contains more than 15% exchangeable Na, or where the Cation Exchange Capacity (CEC) exceeds 6%, which causes the soil to be structurally unstable and disperse into its constituted particles (clay, silt, sand) in water, causing the breakdown of aggregates and lowering the permeability of the soil to air and water. Highly dispersible soils are normally highly susceptible to erosion and are likely to give problems relating to workability and seedling emergence.

These soils can be corrected by using gypsum, a product with soluble Ca, which when added to the soil exchanges with the Na ion when the soil is wet, and makes the soil more stable, and hence better for plants to grow. Gypsum is not a highly soluble salt, and should be mixed with the soil to enhance the chance for the ions to exchange for the quickest response to occur, otherwise the gypsum will have to be leached through the soil's profile for the exchange to occur, which can take some time especially if the sodic layer is deep in the profile. The rate at which to apply the gypsum depends on how bad the problem is, where the sodic layer is in the profile, and the quality of the gypsum, and advice should be sought from an adviser.

Dispersive soils are measured in the field by immersing dry aggregates of soil in distilled or rain water and observing whether the soil disperses or slakes.

Sodic soils can be found in patches across the paddock and hence there is a need to only treat the patches and not the whole field. ElectroMagnetic (EM) Surveys of the field are useful in picking up sodic areas in the field when the survey is done dry, because of excess moisture left from the previous crop, and where the crop's roots have not been able to access this water, the EM figure high. Like all EM surveys, going out into the field is essential to see why the EM figure is high.

2.3.3 Salinity

The way in which plants respond to salted-soil conditions varies, with the tolerance levels between the plants highly variable. The principal harm to plants caused by soluble salts is a reduction in the availability of water. This causes a dramatic reduction in the ability of the roots to access the soil's water supply leaving yields low in these areas. Soluble salts are easily removed from soils, provided they can be leached to a depth that will prevent their return to the rooting zone. The soil needs to be leached of its salts by irrigation, or the salty water table dropped lower. In order for irrigation to occur, irrigated water must be available, and sufficient drainage is needed to allow for the removal of the salt from the root zone. In order to lower the water table trees should be grown in order to drive the water table down through the greater rooting depth of the trees. Where the soil is naturally salty, there is a reliance on the seasonal rainfall to drive down the salt, and the farmer probably has to live with the yield reductions and save money by applying less fertiliser to those areas.

ElectroMagnetic surveys are excellent in picking up these salt effected areas for there will be lots of water left over in the soils profile giving a very high EM reading. Again the survey only tells a difference in soil properties, and it is up the farmer to walk to the problem area and work out what is driving the variability. It has been known that a similar reading in two different areas of a single paddock to be two different problems, with two different solutions, so caution needs to be taken in treating all patches in the paddock the same.

2.4 Overcoming Soil Compaction

Most areas in the world have been having trouble with soil compaction, and few are addressing it. With the large amount of tillage that is being practiced worldwide, there is both plough pan compaction, and a lot of wheel traffic compacting the soil and causing major yield losses. When touring the UK I observed many fields that had waterlogging problems, and many agronomists attributed a lot of this to the high amount of tillage that their farmers were doing, causing soil compaction.

Research into the problem is being done worldwide but it is the Australian researchers who are leading the world, with research and adoption of No-Till and Controlled Traffic systems. It is estimated by Andrew Whitlock, a Victorian Department of Primary Industries precision agriculture agronomist in a recently completed study, that soil compaction may be costing Australian agriculture up to A\$850 million a year in lost production. (Whitlock, 2005) When a soil is compacted it suffers a loss of structure, restricting root access to soil water and nutrient supply; is more prone to erosion and waterlogging; water infiltration is reduced, as is the biological activity in the soil.

In a minimum tillage grain growing system it is not uncommon for equipment wheels to cover more than 85% of the paddock area in a given season and around 50% in a no-till system. However, when Controlled Traffic is implemented, wheels are confined to permanent lanes taking up about 15% of the paddock area. (SAGIT, 2004) When this is put into the context that a single pass of traffic has the effect of decreasing yields by 12 to 17% depending upon what study you look at (Webb et al, 2004) one has an understanding of the desire to minimise the effect of compaction in the soil.

3. Precision Agriculture

With agricultural lands having a large amount of variation, previous farming practice has meant that the only way to deal with this has been to fence according to soil type, and treat each paddock as an individual unit with constant inputs being applied across the paddock. But with farmers striving for increased efficiencies, paddock sizes have increased, as has machinery size. With the cost of GPS equipment coming down dramatically in recent years, farmers have been able to access yield mapping and see what yield variation is actually occurring on their farm, and with the striving for increased efficiencies, and dealing with the cost price squeeze, farmers are now looking at how to best deal with this variability and hence the increased interest in “Precision Agriculture”.

Precision Agriculture includes a range of new and sophisticated technologies. These vary from spray guidance systems, auto steering and controlled traffic systems, variable rate controllers and very detailed information about our paddocks sourced by satellites, yield monitors and survey equipment. These developments are components of a system that has the potential to enhance current practices and offer means to improve efficiency and save labour in farm operations. When collecting paddock information, Precision Agriculture can provide opportunity to balance management with land capability to improve profitability and protect our environmental resources. (Wells, 2005)

Precision Agriculture requires identifying areas of difference in a paddock, going out into the paddock, testing using various methods why the variation occurs, and working out the best way of dealing with this variation to the benefit of the farmer and the environment.

When going through this process it must be kept in mind that all that we are doing is extending agronomy from a whole paddock into a sub paddock level, so collecting sensible and useful layers of data can help of your understanding in what factors are responsible in limiting yield, and how they change with space.

This process is quite sophisticated, with lots of layers of special information being collected, and to get it into a usable form it is important that the appropriate software is used to process the information correctly, and in most cases it will mean passing the information on to an adviser.

A simple way of looking at Precision Agriculture is to look at two different types of problems:

1. **Finding problems that can be fixed and fixing them.** These include using Gypsum to overcome Sodicty, and Lime to overcome Acidity, and using variable rate technology to vary the sowing rate according to the weed density in the paddock. Etc. etc.
2. **Dealing with problems that cannot be fixed.** This is dealing with different water holding capacity soil types including shallow soils, deep sodicity, and salinity. This is where input rates are varied according to the potential of the soil, using variable rate technology.

All of this and more will be explored further in this chapter.

3.1 Precision Agriculture – The Tools.

3.1.1 Yield Monitors.

The ability to monitor yield has been available for a long time, but until the last decade it has come at considerable cost. In England the first yield maps were produced as early as 1907.

These days crop yields may be monitored in real-time during the harvest process, with it being standard practice on most new grain harvesters to have a yield monitor installed as a standard item. The yield monitor once calibrated will be able to tell what yield is occurring in a particular part of the paddock, and when this information is combined with a GPS unit to tell where you are in the field, data collected on a card, a yield map is produced from the data. This yield map is a documentation of the spatial variability in that paddock in that particular year.

The performance and accuracy of the yield monitors from the factory settings are in the order of 2 – 5%, and a higher level of accuracy can be obtained if an accurate calibration on multiple loads, at different flow rates. This requires the operator to follow the manufacturers calibration process.

The manufacturers of Ag Leader and Case AFS yield monitors recommend using multiple grain flow rates to determine or calculate a calibration curve over a range of yield levels. A range of grain flow conditions can be achieved by simply driving the harvester faster or slower than normal, or by driving at a fast speed and taking only ¼ to ½ the normal cutting width. Each different scenario needs its own calibration load; so

multiple loads are needed for an accurate calibration. John Deere has an optional flow compensation calibration as part of their yield monitoring set-up.

In contrast, yield monitoring systems from several other manufacturers (including John Deere – standard calibration, Micro-Trac, CAT and AGCO) should be calibrated with one load of grain that is harvested under conditions similar to those expected during operation and data collection. Determining a zero reading when no grain is being harvested completes calibration. Before using the data from any yield monitor, weigh at least six separate loads either for the initial calibration or re-check the calibration after a period of use.

Grain yields estimated by yield monitors are adjusted to account for differences in grain moisture and are reported at standard grain moisture. Most systems estimate grain moisture from a continuous measurement of the electronic conductivity of the grain at a given temperature. Moisture sensors have a grain temperature sensor that modifies the moisture calibration. Because of this, a calibration of the temperature component is important, and often overlooked, in order to get an accurate moisture and yield reading. John Deere allow you to save a moisture reading, test the actual grain moisture from that reading, and adjust for any differences.

Yield maps are a very important part of Precision Agriculture and hence require good information from the monitoring process to be worthwhile. You only have one opportunity each year to collect the data, and so correct set-up is essential. Many yield maps have been spoilt by incorrect set-up with valuable data lost by not spending time on the set-up process.

The first step in setting up the yield monitor is making sure the presets are correctly installed, these include the correct machine-model, comb type and size, comb stop height for each grain type, GPS configuration and logging interval, and lastly crop type, paddock name, and load number. These should be all done prior to harvest to ensure that harvest runs smoothly. Also prior to harvest, stop height, distance, and temperature calibrations should be done. When first harvesting each crop, each year, grain calibrations should be done, for grain flow conditions change from year to year, as do the mechanics of the yield monitor. Also prior to harvest it probably is a good idea to see if the GPS is logging correctly onto the card. To do this connect the GPS and run the harvester empty while moving. This will log a zero yield over a distance, which can show up on the pre installed basic mapping program.

The make and model presets are important because they include the “time-delay” calibration. “Time delay” is the time taken to move through the machine from the front of the harvester to the grain flow and moisture sensors. This figure varies from 6-20 seconds depending on the type of harvester used. This time delay must be accounted for to get “geographically-correct” yield and moisture maps.

Once harvest commences, it is a good idea to get into the habit of downloading the day’s harvest each night onto the home computer for a backup, and if there is a problem with the day’s data, only one day’s data can be lost, not a weeks data.

On the home computer the data should be filed under the appropriate year, paddock folder to enable quick access to the files when further data processing is to be done. Good filing systems means good business.

As I was travelling from country to country, most Precision Agricultural companies/groups ran training courses on correct data collection from the harvester to the home computer file.

3.1.2. Protein Sensors.

There has been a need for protein to be measured on the go like yield for a long time because of its relationship with Nitrogen usage. I.e $\text{Yield} * \text{Protein} = \text{Nitrogen removed}$.

CASE tried to bring a protein sensor on the market a few years ago but it is rumoured that they had trouble with its accuracy, particularly with calibration, so they withdrew it from the market.

There are two commercial protein sensors on the market in Australia at the moment with NIR Technology Australia releasing the **Cropscan 2000H** two years ago and have it working in the field, and the Zeltex **AccuHarvest On-Combine Grain Analyzer**.

NIR’s Cropscan 2000H

This system takes a reading every 6 seconds, and measures protein and moisture using NIR (Near Infrared) technology similar to the testers that are used at the commercial silo sites. The system consists of an NIR Spectrometer, a Remote Sampling Device, and a Remote PC Display and Controller. The Spectrometer and the PC Controller are

mounted inside the header cabin, and are connected to the Remote Sampling Device using Fibre Optic Cables. The Remote Sampling Device is fitted to the bubble auger in the header bin. As the grain moves up the bubble auger, the sampling device traps the grain in a sample cess. NIR light is passed through the grain and collected by the fibre optics on the adjacent side. The NIR light is transmitted back to the NIR Spectrometer for analysis. Protein and moisture are computed and sent to the PC Controller where the data can be displayed as a moving average, bin average, a trend plot or even as on the fly paddock maps. Yield and GPS signals can be fed to the PC Controller so the complete paddock maps can be displayed and stored.

Talking to a couple of growers who have fitted it to their harvester I heard there have been problems with the catching and releasing of the grain coming out of the bubble up auger, and hence the reliability is sometimes questioned, but once the grain is tested the system works OK. The company is working on the problem at the moment and results from the modifications will be available at harvest time this year (2005).

The Zeltex “**AccuHarvest On-Combine Grain Analyser**”.

This new grain quality sensor measuring protein and moisture on the go was presented at the 5th European Precision Agricultural Conference on June 9-12 in Uppsala, Sweden, and is now sold by Zeltex, Inc. This sensor was developed by the Australian Centre for Precision Agriculture, in conjunction with growers in Conservation Farmers Incorporated, in collaboration with Zeltex Inc, and the Swedish Institute of Agricultural and Environmental Engineering, has been tested for the last two seasons in Australia under Australian conditions.



Figure 4. The Zeltex “AccuHarvest On-Combine Grain Analyser.

The grain quality sensor is mounted on the harvester’s clean grain elevator. Depending on the harvesters ground speed, the sensor automatically samples grain four or five times per minute. The sensor works by sampling grain from the up elevator shaft and depositing it into the down elevator shaft. The inlet and outlets are controlled by two trapdoors. When grain enters the chamber and both trapdoors are closed, NIR light is transmitted through the grain sample, which is recorded, and then the outlet trapdoor is opened letting the grain out. The cycle is then repeated.

There have been difficulties getting it to work in the dry, dusty, Australian conditions, and it has undergone some hardware and software modifications from the original prototype.

When I visited Jim Wilson from Scotland he was in the process of fitting one to his harvester, and after a few electrical problems got it to work very well and was very pleased with its performance. Below are few of his maps.

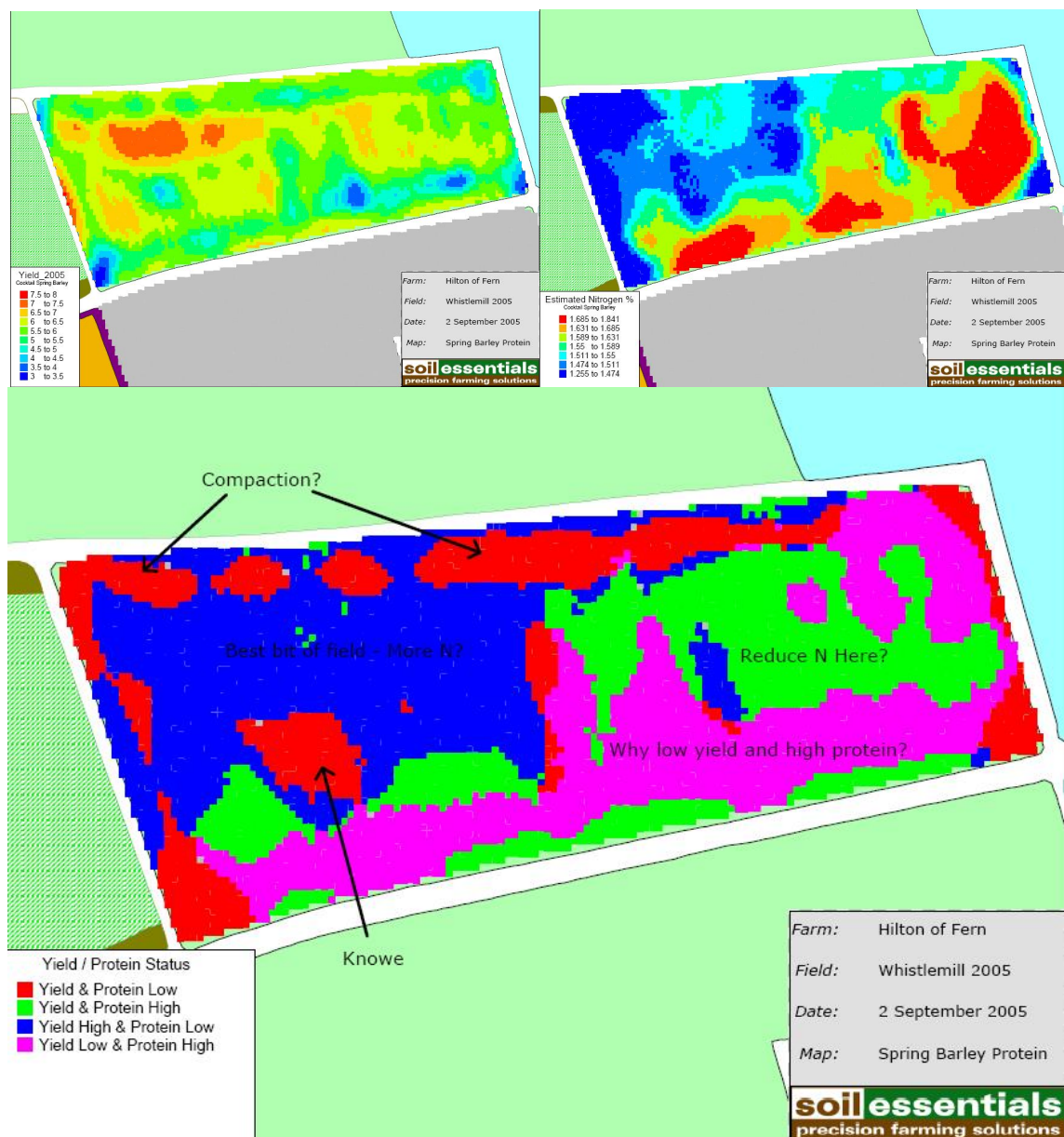


Figure 5. Maps of Jim Wilson's paddock using the Zeltex Protein Sensor, and analysis from Scotland.

3.1.3 Soil Mapping.

When soil properties change in a paddock it can have a dramatic effect on the yield potential of a particular crop. To have the ability to map these changes in soil conditions is a very important part of the Precision Agriculture jigsaw because of this potential relationship. Bare soil photos, aerial photos using different wavelengths, and other remote sensing techniques have been used to map soil changes, but depending on the technique used, looking at the surface of the soil only has limited application, for a lot of the soil properties correlated to yield are at a depth, and hence techniques that have the ability to look into the soil at a depth are a lot more beneficial in Precision Agriculture.

Early Precision Agricultural work done overseas attempted to find out this information by directly sampling the soil on a grid, but to get accurate information the grid has to be at least 4 per hectare and the sampling should be taken at different depths. This information is too expensive to collect and in most cases has been abandoned, in favour of cheaper methods.

Electro Magnetic Induction and Soil Electronic Conductivity techniques are favoured in soil mapping because of their ability to penetrate the soil at different depths and identify areas of contrasting soil properties. Both methods effectively measure electronic conductivity (EC) of the soil at different depths, and when combined with a Global Positioning System (GPS) the EC readings can be logged with precise locations across the surveyed area. This data can then be processed to produce a map that infers variability in the root zone across the paddock. This map provides the foundation for investigating and gaining a sound understanding of where soil properties may be varying in a paddock and their agronomic significance.

Factors in the soil, which can affect the EC reading, are; Moisture content, Soil Texture (especially clay content), Electrolytes in the soil solution, and Soil bulk density. The clay content of the soil is especially important, for soils with high percentages of clay tend to hold more water than those dominated by sand, and hence it is a key ingredient of productivity. The amount of electrolytes in the soil solution, ie salinity, is important because of their potential to effect productivity in a negative way. Soils that are compacted will have a higher soil bulk density, and hence the EC reading might be able to pick up compacted areas if other factors don't dominate the reading.

Due to there being a number of factors that will affect the EC reading, “ground truthing” is a must to determine if there are any relationships between it and the actual soil profile characteristics.

The map provides a guide as to where soil samples should be collected by indicating where the trends in conductivity exist, therefore inferring a change in soil profile conditions. Soil samples should be collected close to when the survey was conducted to analyse the soil chemical and physical properties in regions delineated by the map.

In France the Co-Operative “Epis Centre” uses EC maps to produce a sowing rate map where sowing rates are increased according to how stony the ground is, for they expect lower establishment percentages in stony ground. These soils have a low EC value due to lower moisture content in the stony soil. This was also mirrored in England, and farmers around York were using the information to see how their drains were performing, and identifying if any were blocked, so they can be fixed and so increase the drainage on their soils. In this case a very high reading would be observed because of the high amounts of water in the profile. SOYL the biggest Precision Agricultural company in the UK are large users of Electrical Conductivity surveys.

On my trip I came across three systems that were able to “on the go measure”, directly or indirectly, Electronic Conductivity and they were Geonics **EM-38**, the Verris **Soil EC Surveyor 3100**, and the **GEOCARTA** from France.

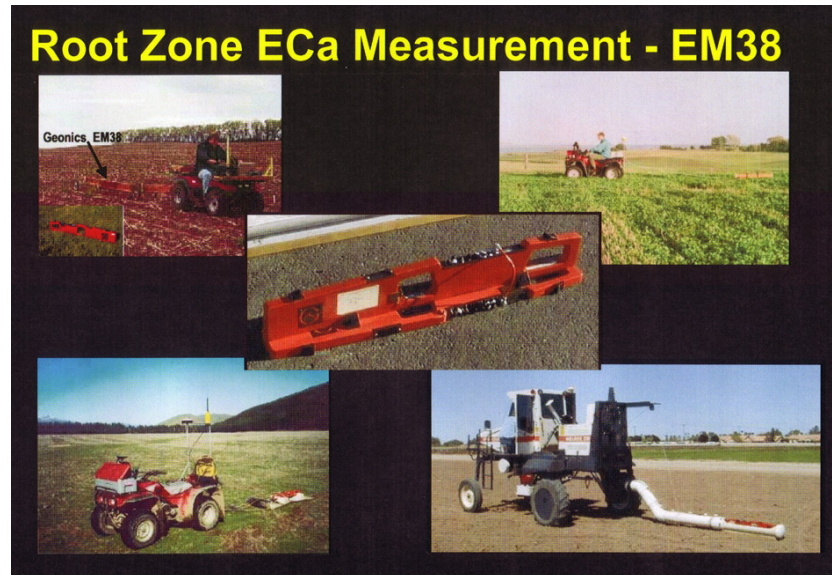
Geonics EM38

It is an Electro Magnetic Induction sampler that when powered up emits an electromagnetic signal which passes down through the soil profile, generating a second magnetic field in the soil that varies depending on the soil’s properties, and the second magnetic field strength is detected by a receiver on the EM38 measuring the apparent electrical conductivity (ECa) of the soil profile.

The Geonics EM38 has an energy field, which extends mostly vertically from the instrument to a distance of approximately 1.5m depending on what is nearby the sensor. This energy field also extends horizontally but only to an approximate depth of 75cm. When the EM38 is positioned upright on it’s edge, or in vertical mode, the response is mostly sensitive to the soil at 60-150cm. When laid on its side, in horizontal mode, the response of the EM38 is influenced more by the surface soil conditions at 0-60cm.

Figure 6.

The Geonics EM38.



Verris Soil EC Surveyor 3150

This is a series of 4 discs which are pulled through the soil, one pair of counter-electrodes injects a known voltage into the soil, while the other counter-electrodes measures the drop in that voltage, effectively measuring the soil's electrical conductivity (EC) at two depths, 0-30cm and 0-91cm simultaneously.

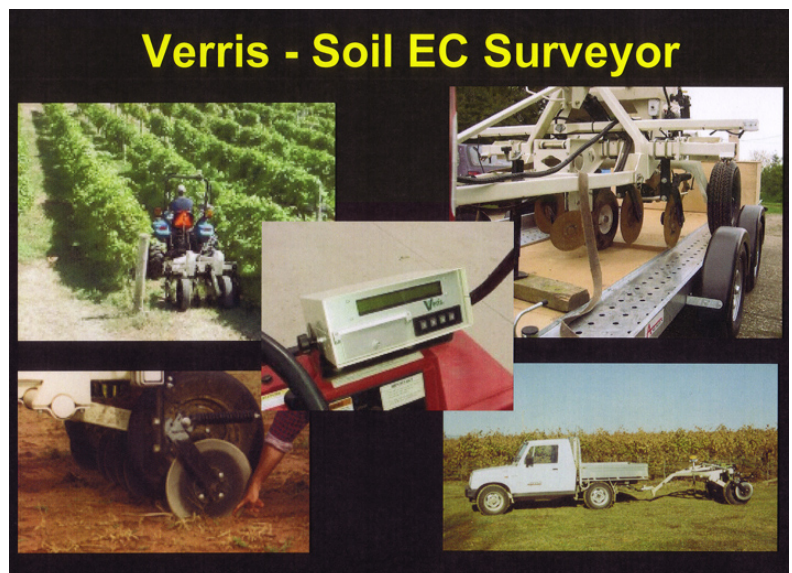


Figure 7. The Verris Soil EC Surveyor from the USA.

GEOCARTA ARP

This uses similar technology to the Verris sensor, but has 6 disks and measures 3 depths simultaneously (0-0.5m, 0-1m, 0.2m). They operate on 12m swathes, and can travel up to 20ck/hour, and do 100 Ha a day. After they gather the information, and do soil sampling according to the change in EC information, they are able to generate texture maps, soil depth maps, stone maps, and P rate maps. From their Soil depth maps they are able to generate a Potential yield map, which is used for their Nutrient Budgeting.



Figure 8. The GEOCARTA ARP from France.

There are many more methods being researched throughout the world in On-the-Go Soil Sensing, and although some of them have gone to commercialisation, they currently hold a very small part of the market. These include, Subsurface Soil Reflectance Sensors, Microwave Sensors, Ground Penetrating Radar, Soil Mechanical Resistance Profilers, Soil Penetrating Noise Sensors, Air Permeability Sensor, and Electrochemical Sensors. The ongoing research into these types of sensors will continue, and possibly replace the EC sensors in the future.

3.1.4. pH Mapping

The two commercial platforms for on-the-go pH testing that I came across were the Verris pH Manager, from USA and the yet to be named on-the-go Soil pH and Lime Requirement Measurement System (SpHLRMS) developed by the Australian Centre for Precision Agriculture, the Swedish Institute for Agricultural and Environmental Engineering, and Computronics Holdings Limited from Perth Australia.

Verris Soil pH Manager

The Verris Ph Manager automatically collects and measures a soil sample every 10-12 seconds. It operates by having a row cleaner at the front of the platform that clears away any crop residue, while a firming wheel presses loose soil to optimise soil flow into the sampler. The sampler hydraulically lowers into the soil and soil flows into a sampling tube. The sampler is raised, bringing the soil sample core into contact with a ion-selective pH electrode. After 8-10 seconds of stabilisation period pH data is logged on

the Verris instrument, and another cycle is started. During each cycle, the electrodes are washed with water from a tank stored on the platform. The furrow is then covered with closing disks.

This sensor was developed at Purdue University in Indiana USA.

Figure 9. The Verris pH Sampler shoe.

Verris sells a Mobile Sensor platform (MSP), which combines both the Verris EC Surveyor 3150 and the Soil pH Manager into one platform, and so pH and EC data can be obtained simultaneously.



Figure 10. The Verris Mobile Sensor Platform.

Kevin Hope from TCS UK Spraying uses the Verris Mobile Sensor Platform as part of a contracting business. He is aiming for a sample every 40 square meters, which is the base for accurate mapping. He can also get more accurate if needed by slowing down.



The machine cost \$A42,500 to set up on a trailer.

Contracting charges are \$A6.8/ac for 40 square samples and \$A7.5 for more accurate 20 Square sample maps.

There are problems as the equipment needs high maintenance, with the probe continuously wearing out and this costs 50p in regular replacement costs.

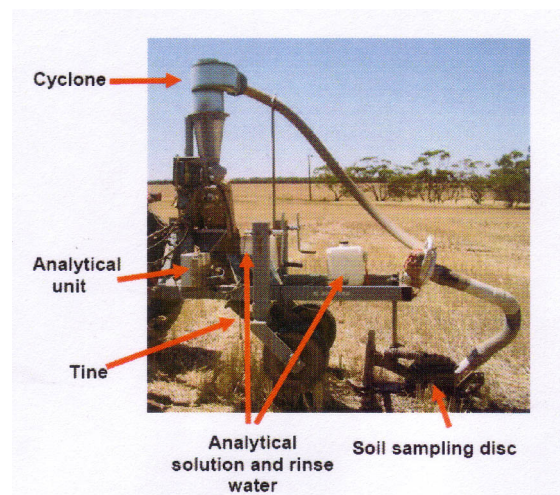
Verris are working on an improved MSV that would measure potassium (K) and nitrate, as well as buffer pH.

Soil pH and Lime Requirement Measurement System (SpHLRMS) (Buffer pH Sensor)

The buffer pH Sensor uses a tine to loosen up the soil to be sampled. The sampling mechanism consists of a self-propelled 30cm waved spinning disc that is used to throw soil up from the top 10-20 cm soil layer. A flat metal piece is used on either side of the sampling disc to ensure that straw, large stones and other trash is not sampled. Soil is aspirated by a materials fan to a cyclone at approximately 30 m/s. When the soil goes through the fan, it is broken down into smaller particles and pulverised. The soil then drops into a rotating sieve that ensures only soil with a size fraction of 2mm is passed down to a volume-measuring unit, which measures 4cm³ of soil. A sliding mechanism is used to transport the measured soil into the analytical component where the soil is mixed with the analytical solution inside the mixing chamber. The pH is then measured and logged. Thereafter, the chamber is rinsed with water ready for the next sample.

Not only does the sensor measure pH but it also provides lime requirement estimates.

Figure 11. The “on-the-go” soil pH and lime requirement measuring system being developed at the Australian Centre for Precision Agriculture.



The first field trial was done in Western Australia last summer and showed promising results, but improvements need to be made in improving the soil pH measurements for there was a little difference between the lab results and the sensor's results.

A second prototype is being developed which will improve the accuracy and will hopefully bring the sampling time from every 27 seconds down to 13 seconds. (Taylor et al, 2005)

3.1.5 Elevation Maps

Elevation is a vital layer in Precision Agriculture for providing elevation, slope, and aspect maps, and it is important in understanding the influences on water infiltration and yield variation based on direction of slope.

Elevation can be obtained by averaging DGPS maps over a number of yield maps, or now with 2cm RTK GPS systems becoming popular, this is becoming the preferred method of mapping elevation because of its higher level of accuracy. The contractor I use to obtain EM surveys uses a RTK GPS in order for the accurate elevation layer to be collected.

This coming harvest the CASE AFS system and the John Deere system for collecting Yield data will be able to log RTK elevation as part of the data collected at harvest time.

KEE technologies have released elevation mapping as part of their variable rate program.

3.1.6. Remote Sensing

Photography has been used for aerial surveillance for well over a hundred years with cameras being strapped to everything from tethered balloons to carrier pigeons in the mid 1800's. During World War I airplanes were used to carry cameras for military purposes. By the 1940's, the USA Soil Conservation Service was routinely collecting aerial photography primarily for the compilation of early soil surveys. Since this time, there have been considerable advancements in remote sensing technology such as colour-infrared photography, digital cameras, thermal infrared sensors, and satellite imagery.

The view of an agricultural paddock is typically done from ground level, or at best, from the seat of farm machinery. While this ground level view of a paddock will never be replaced, the additions of a "birds eye" view can greatly enhance a grower's ability to make informed management decisions about their paddocks. More specifically, paddock knowledge coupled with a better understanding of factors potentially affecting crop yields. Examples of benefits obtained from basic remote sensing include; Soil Type changes, early weed detection, crop establishment problems, Moisture stress in a crop, Farm Equipment patterns including compaction problems, Lodging problems, Crop disease detection and many other factors effecting yield.

New advancements in remote sensing include sensing the nitrogen status of the crop by using a series of different wavelengths in different ratios to determine how healthy the crop is, and provide nitrogen recommendations to optimise crop yields.

A common approach used by researchers to assess vegetative health within agricultural paddocks is the calculation of vegetative indices. These indices are calculated by mathematically manipulating (or ratioing) the infrared reflectance in digital image with the red reflectance resulting in a new indexed image. This index image is comprised of numerical values that represent the relative condition of a crop, i.e. plant biomass. The most popular of these indices is the Normal Difference Vegetation Index (NDVI) equation.

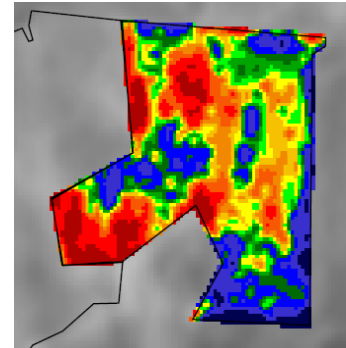
$$\text{NDVI} = ((\text{nir}-\text{red})/(\text{nir}+\text{red}))$$

Nir = Near Infrared Reflectance.

Red = Red reflectance.

The output of this process is an image showing the variation of plant condition throughout the field whereby red indicates areas that are the healthiest (or most biomass) and blue the least healthy. There are many other indices used in agriculture, it depends what information the researcher is trying to gather.

Figure 12. NDVI of Blackflat taken from a EADS Satellite, 2nd September 2005 as part the Farmstar program. Processed by Terrabyte Services, Australia.



3.1.7. Satellite Imagery

Satellites orbit above the earth at up to 700km, capturing information from sensors focused on a particular area of the earth's surface.

Satellites have an advantage in that they continuously take images over a large area giving information throughout the growing season, but have a disadvantage in that it cannot see through cloud cover, and hence has limitations in collecting information during the winter where cloud cover is expected.

There are different types of satellites that are able to capture information, and depending on the spatial resolution, the cost of acquiring this information varies. Spatial

resolution refers to the spatial extent of the sensor. The information gathered by the sensor is split into “pixels. A Pixel is the smallest unit of an image, and contains colour data related to what is found within that defined area. Higher pixel size usually means the sensor needs to be nearer to the ground. Some satellites provide high-resolution images with 0.6m pixel sizes (e.g. Quickbird, IKONOS), while other satellites provide images with a coarse resolution of 30 m (e.g. Landsat 5). The higher the pixel size the higher the cost of acquiring the imagery.

The image obtained needs to be Georeferenced, Orthorectified, and corrected for atmospheric variations, and the more this is done, the cost of the image increases.

LANDSAT

JG Boswell Cotton farm in California were acquiring 7 seven images / year from the Landsat 7 Satellite which is a Satellite collecting 30 m resolution images. They use it to look at the crop and any potential problems, as well as using it to see how the previous history of the paddocks is affecting this year's crop, and learn from this history. They have been also been able to pick up drainage, compaction and disease problems in the previous year's crop.

Guy Lafond from Indian Head Research Centre in Saskatchewan Canada uses 3 years of Historical NVDI maps from the Landsat satellites to make Management Zones, as does Silverfox in Australia.

FARMSTAR

In France I visited the company EADS Astrium (European Aeronautic Defence and Space Company) which is the second largest aerospace company in the world, to look at the FARMSTAR program which is used by French, UK, and hopefully Australian farmers to aid crop decision making.

Farmstar started as collaboration between EADS and the wheat institute of France. It undertook 4 years of development in France, from 1996 to 1999, 2 years to validate, and in 2000 it went commercial. It has now been going for 10 years. Last year in France it had 6,000 farmers using it on 180,000 ha and this is expected to expand out to 250,000ha next year. Even though there are a lot of farmers using it, out of the 6,000 farmers using it this year, only 30 farmers are using it for Variable Rate Fertilising.





Mark Branson

The satellite measures the Chlorophyll content of the crop, which is correlated with the Nitrogen status of the crop, and the Leaf Area Index (LAI), which is highly correlated (90%), with the canopy status of the crop. From this information EADS is able to tell the Plant Population, Biomass and Nitrogen status of the crop, and from this is able to inform the farmer/adviser the tiller density in the crop, and recommend Nitrogen rates for numerous stages of the crop's life and also the lodging risk of the crop. Because the acquisition pixels are done in 20m grids, they are able to recommend different nitrogen rates for different parts of the fields.

Farmstar uses 3 EADS spot satellites, spot 2, 4, and spot 5, taking 4 bands of information which has the ability to theoretically visit every 4 days, but acquisition depends on having a cloud free day for the satellite to see the field. They are able to point the satellite's cameras to an area if it is close to the flight path. EADS corrects the information from the satellite and takes out the background information such as; atmosphere, soil reflectants, angle of the picture, and leaf angle difference, which is why they are able to get accurate information to the farmers, that is better, in their opinion, than their competition.

For each field Farmstar needs a field boundary, variety sown, sowing date, sowing density, and the type of soils that are in the field. They need research done on each variety for each variety needs a different reference curve to get an accurate LAI.

Table 2. Farmstar's 2004 wheat package for Europe.

Growth Stage:	GS26	GS30	GS32 - 33	GS39
Approx date:	Mid-February	Late-March	Late-April	Early May
Crop Architecture:				
Maps delivered to grower:	<ul style="list-style-type: none"> •Shoot Density •1st Nitrogen •GAI (1) 	<ul style="list-style-type: none"> •Fertile Tiller Density •Main Nitrogen •GAI (2) 	<ul style="list-style-type: none"> •Lodging Risk (2nd PGR) 	<ul style="list-style-type: none"> •Final N •GAI (3)

In France the wheat package includes 3 acquisitions, GS 26, GS 30 and GS 39, and from this information they recommend Nitrogen rates at these three stages, and a Lodging risk map at GS 32, in time for the second Plant Growth Regulator spray, which

is produced from the GS 30 acquisition. At the first acquisition they provide a Nitrogen budget from the amount of Nitrogen that has already being absorbed by the crop. Also from the first acquisition they are able to tell if there are any bad weed areas for they have an abnormally high biomass for the growth stage of the crop.

The information is provided to the farmer/adviser through the post, email or Farmstars internet site with a protected code.

The Co-operative Epis-Centre who uses the Farmstar program as part of their Precision Agricultural package estimates gains of A\$50/ha to A\$100/ha.

Other than wheat, the Farmstar program is used in Barley, Canola, Corn, Soyabeans, and Sugarbeet.

FARMSTAR in the UK:

Infoterra is an EADS company responsible for implementation in the UK with its project manager being Gary Holmes.

The use of Farmstar in the UK is using Gavin Woods work for HGCA, which uses the armstar information to correct Green Area Index (GAI) using Nitrogen when the crop falls outside the optimum yield response GAI curve. Wheat provides optimal yield when GAI development is close to the reference GAI growth curve.

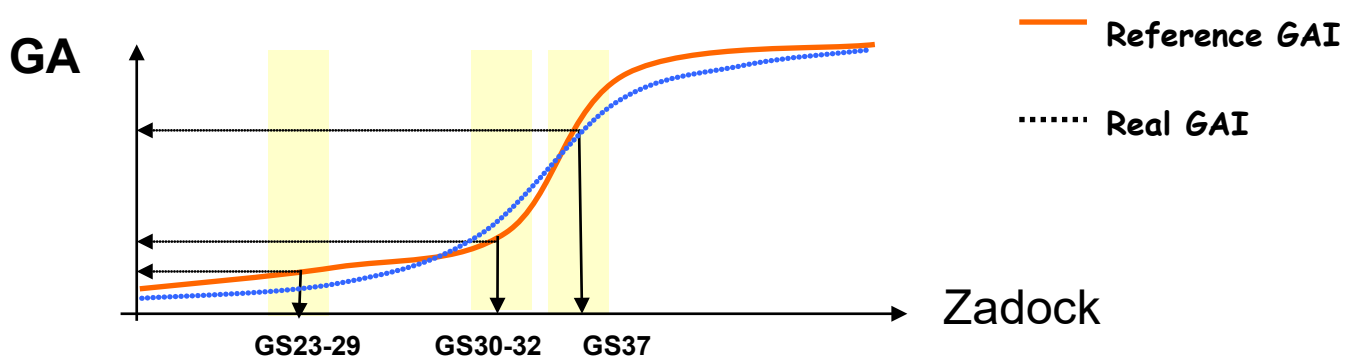


Figure 13. A graph representing the use of Green Area Index (GAI) for recommending Nitrogen application rates, to manipulate GAI, at three key growth stages.

The first acquisition at GS 26 is used to correct for deficiencies in shoot density, for which they are aiming for 450 to 600 tillers, and N rates vary according to whether they need to build or maintain shoots.

The second acquisition and main Nitrogen application uses the Farmstar to vary Nitrogen according to whether the crop is in the optimum GAI range for the crop at the Growth Stage 30. This recommendation is based on the instantaneous GAI value and stem density observed in the previous acquisition.

The last acquisition at GS37 corrects last shifts of real GAI to the theoretical value.

Testing of the service has been done by Cranfield University and has been found to be reasonably accurate.

The Nitrogen methodology verification gave a 10% yield response to reduced Nitrogen, and a 19% yield response to increasing Nitrogen in below target zones, but I find these results surprising, and so did Gary.

The HGCA estimation of following the Cranfield recommendations on Variable Rate Nitrogen using the above method puts the economic gain at A\$55/ha in gross margin, with an environmental gain of a third reduction in leachable nitrogen.

The use of the Lodging Risk maps is seen as a big winner with major decreases in lodged crops with the targeting of PGR's at the appropriate timing, GS32.

They have trouble with continuous cloud cover most years, and have airborne and ground rig (Yarra N sensor) backup.

Turn around time from acquisition time to recommendation maps is 4 days, so the ordering of acquisition needs to be planned out well in advance. At this stage the satellites take a 60km square photo, so it is up to the service provider to get as many farms in this photo as possible.

FARMSTAR in Australia:

While I was with Bernard, a validation project in Australia was being talked about with GRDC using Terrabyte services from Australia and EADS Astrium to fund such a project. Hopefully this will get off the ground next year. This will take the form of various levels of entry ranging from one acquisition and very basic information, to 2 acquisitions with an advanced agronomic practice, which will need some validation. They are going to attempt to validate a package for Wheat, Barley and Canola. They are very keen to work on applying their technology into different zones with different yield targets.

I believe that this system has a lot to offer growers in Australia for it gave nitrogen recommendation maps based on very good science and should be able to acquire more maps than in the UK and Europe because we don't have as much cloud cover as they do.

GEOSYS

The second satellite-based company based in France is Syngenta's company GEOSYS. This company was a split from EADS and hence has very similar services. They have a presence in France, UK, and the USA.

They offer an online service where crop information is put on the web; the farmer pays an annual subscription to have access to the satellite image at any time of the year. With the package you get a software programme for the farmer to enter the paddock information required to generate nitrogen recommendation maps derived from the Leaf Area Index (LAI) gained from the satellite.

The system costs a little less, but according to EADS Astrium they use satellites that are not as good as the EADS's SPOT Satellites, and they don't correct the logged data for Atmosphere, Soil Reflectance, Angle of the Picture, and Leaf Angle Difference as well as the Farmstar system. Despite this they offer a complete service at a very good cost because they effectively cut out the "middle man" by running an Online service.

SOYL, in the UK use their service and were very happy with it although, like the Farmstar system, they have trouble with cloud cover.

3.1.8 Aerial Imagery

Aerial photography offers the same service as the satellite information except they are able to get better resolution by being closer and they have the ability to swap sensors and use Multi-spectral or the better but more expensive Hyper-spectral sensor.

Jerry Hatfield, director of the National Soil Tilth Laboratory told me that there is being lots of research being done into hyper-spectral sensing and looking at identifying different weeds, including the ability to pick out ryegrass from other plant species. I believe this information will be of great benefit in the control of resistant ryegrass.

There are many companies that use aerial imagery with John Deere entering the USA market, Spoeckterra and HyMap/HyVista in the Australian market.

3.1.9 Ground Sensing

I believe this is where the future will be for Precision Agriculture for it provides the opportunity for on-the-go management decisions to be made. It also allows for multiple acquisitions to be made in a single year, and doesn't have the problems with cloud cover, unlike all of the other methods.

Ground remote sensing involves mounting a sensor on a vehicle or trailer, and driving through the crop with the sensor looking down into the crop and gathering reflected light back from the crop. They need a light source to operate and this comes either from the sun or from the sensor itself.

By having to drive through the crop those who operate a controlled traffic or tramline systems have an advantage, especially if acquisition is needed late.

Most of these sensors operate in Real time, but if you put a GPS in the system, you can map the sensed information to look at later, and variable rate your input after some ground-truthing is done.

There is a lot of research being done worldwide into these types of sensors, and I predict that in the future we will see an explosion of them coming onto the market.

Yarra N Sensor



Figure 14. The Yarra N Sensor mounted on a Househam self propelled boomspray at York, England.

This sensor has been around the longest and has the greatest amount of research done on it. There are over 200 sensors in Germany, and 58 sensors used in the UK.

An Optical Sensor mounted up above the cabin of the tractor, sprayer, or other mobile vehicle, measures and analysis the sunlight reflected by the crop. It also measures the

ambient light, and corrects different light conditions. The sensor takes measurements of biomass and chlorophyll content of the crop in a very similar way to the Farmstar and Geosys satellite systems. These measurements are then used to better manage the crop on a variable basis.

Sensing the crop at different growth stages allows for variable Nitrogen fertilizing (with recommendations) variable applications of fungicides (according to differences in biomass), variable application of growth regulators (according to differences in biomass), variable application of Reglone, more efficient harvest, Protein prognosis, and markers which make it possible to optimize other applications.

The variable Nitrogen fertilizing uses a mixture of the Biomass reading and the chlorophyll content to attempt to even up the crop in the field. Where the crop is thin and lacking chlorophyll, the N-Sensor recommends and applies through a variable rate applicator an increase in the Nitrogen being applied, and inversely, if the crop is thick and high in Chlorophyll. But if the crop were thick and low in Chlorophyll then an average amount of Nitrogen would be recommended.

When entering a field you drive to an pre determined part of the field where a spot nitrogen calibration is done, put in a recommended rate for that area of the crop, a high and low rate cutoff, and then drive the rest of the field with the sensor on-the-go changing the nitrogen rate according to how the sensor sees the crop.

The sensor looks forward and back and continuously scans 50 m³ each second, a larger area than all other ground sensors.

It has been shown over a number of years of trials and experiments that this method has increased by 3% and being more environmentally friendly by putting fertilizers where the crop needs them, and backing off where there is ample Nitrogen already in the crop.

It also has the effect of higher and more homogenous grain protein content and quality of the grain. Also the harvest ability of the crop is increased with a more homogenous crop, more uniform ripening, more uniform grain quality, and less lodging.

Fungicide and Plant Growth Regulators trials are being done at the moment and are looking very promising, with the aim to put an equal amount of active ingredient on each leaf according to changes in the biomass of the crop. This relationship is; for every increase in Leaf Area Index (Biomass), there is a 15% increase in the rate of chemical.

Yarra in Germany estimate the economic benefits of using the N-Sensor in 2004 are as follows:

Cost of investment (5year investment)	A\$7875
Cost of repairs	A\$ 160
System Updates	A\$ 720
<u>System Checks</u>	<u>A\$ 560</u>
Total Costs	A\$9315

Over 250ha Wheat area = A\$37.26/ha

Benefit savings for Winter Wheat yielding 8t/ha, A\$144/t. Combine costs A\$144/ha, N rate 200kg/ha costing A\$0.96/kg N, in Germany.

Yield Increase (3% = .24t/ha)	A\$34.56
Fertilizer savings (10% reduction = 20kg/ha)	A\$19.2
Increased Combine performance (15% increase)	A\$21.6
Decrease in Lodging Risk (avoid 30% of the field)	A\$15.55

(10% yield reduction and 50% increase in thrashing performance)

Benefit per hectare per year	A\$90.9/ha
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Transferring these benefits to Australia in 2005.

Assumptions, APW Wheat yielding 4t/ha, A\$150/t. Combine costs A\$45/ha, N rate 60kg/ha costing A\$0.45/kg N.

Yield increase (3% = .12t/ha)	A\$18.00
Fertilizer savings (10% reduction = 6kg/ha)	A\$ 2.70
Increased Combine performance (15% increase)?	A\$ 6.70
<u>Decrease in Lodging Risk (avoid 2% of the field)?</u>	<u>A\$ 1.00</u>

Benefit per hectare per year	A\$28.4/ha
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In summary the N sensor is profitable in Germany, but when you transfer it to Australia, you would need to grow and variable rate 665ha of wheat to get a return on investment of 2 times.

Also trials into varying Nitrogen on Canola and Barley are being done at the moment with the effects on yield, oil content, and protein being investigated.

In Australia we are using one in SPAA for trialing purposes, with GRDC funding the research and last year there was a 3% increase in yield by using it, which is similar to the findings for the rest of the world, but at the cost of A\$34,000 you would have to do a very large area with it to make it pay. As a research tool I think it has great merits, with the ability to scan the crop multiple times during the year giving the researcher the ability to learn about the correlations between differences in canopy structure and final yield in the Australian conditions.

A major problem with the sensor is that by using the sun as its active light source, it can only be used during the hours in the day where the sun is up high to get the correct angle of light reflected off of the leaf. These hours during the winter in South Australia are between 10.00am and 4.00pm. To overcome this problem there will be a new Yarra N Sensor released next year with its own light source, so it will be able to be used at any time of the day. It is also going to use wireless communication between the sensor on top of the cabin, and a PC based monitor in the cabin, getting rid of cables.

N-Tech – GreenSeeker

Figure 15. The N-Tech Greenseeker ® mounted in Indian Heads Research Farms boomspray in Saskatchewan, Canada.



The GreenSeeker ® has been developed by Bill Raun and others at the Oklahoma State University, and is now made and sold by NTech out of Ukiah California and has been researched for 14 years so it has a bit of research behind it.

The GreenSeeker ® emits its own light source to measure the reflectance of specific wavelengths of light (red and Near-infrared) off the crop canopy. By having its own light source it is able to work under any light conditions and is not restricted by the sunlight hours like the Yarra N-Sensor. The computer system within the sensor uses canopy

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reflectance to calculate NVDI, which is a number between -1 and 1 and is a measure of the crops above ground biomass. Pavement has an NVDI of about 0 , while healthy wheat crop at the 5-leaf stage would have an NVDI of about 0.6 . By dividing the crop's NVDI value by the number of growing degrees accumulated between seeding and sensing, the growth rate of the crop is calculated. This value, which is referred to as In Season Estimated Yield (INSEY) is then entered into a logarithmic equation based on previously collected field data to estimate the yield potential of the crop. Determining the yield potential of the crop early in the growing season is a key factor in determining the optimum amount of fertilizer to apply.

The system works by applying a small amount of fertiliser at seeding time, enough to cover a poor year, and use the sensor to post apply nitrogen, preferably after GS 31. In a small part of the paddock, Nitrogen needs to be applied at a high enough rate for the nutrient not to become limiting prior to the scanning of the crop. This is called a N-Rich strip. This needs to be done in each paddock where the system will be used. By visually comparing the N-Rich strip with the rest of the paddock, the farmer will have a good idea of whether or not they should be topdressing N. However, the human eyes are limited in their ability to detect small changes in colour and biomass accumulated, while the GreenSeeker® sensor is not.

When the timing is right for the topdressing of N, the farmer needs to scan both the N-Rich strip and an area alongside. If the two numbers are approximately the same then there is no likely benefit of topdressing at that time, but if the NVDI of the N-Rich strip is higher, top-dressing N is recommended.

The NVDI of the N-rich strip, along with the growing degree-days accumulated between seeding and sensing, are then entered into software used by the system. These figures are compared to the paddock's NVDI values, which are fed into the algorithm in the software, which provides new nitrogen recommendations for each NVDI value.

The default algorithm in the software is for use in the Mid-West states of USA, and it is recommended that new algorithms be developed for each new area that it is used.

I met two groups who were developing algorithms by using the GreenSeeker® RT 200 for their areas. They were the Virginia Coastal Plains group, Virginia USA, and Indian Head Research Farm, Saskatchewan Canada.

After one year's research into the Virginia algorithm, the Virginia Coastal Plain group has achieved similar yields to standard tissue test recommendations, but at 2% better Nitrogen Use Efficiency (NUE) on their new GreenSeeker® Virginia Algorithm, and a 10% lower yield, but a 9% better NUE on the GreenSeeker's® own algorithm. This indicates that in the very wet Virginia area the GreenSeeker® algorithm was underestimating the amount of N needed to achieve optimum yields. Research and adjustment into the Virginia algorithm is ongoing and expected to continue for a number of years. This research is being conducted on 4 different sites, and all sites show similar trends.

At the Indian Head Research Farm Guy Lafond and Chris Holzapfel are running a research project "Optimising Nitrogen Fertilization through Remote Sensing Technology" where they are evaluating the use of the GreenSeeker® RT200 for spring wheat and canola crops. The main goal of this research is to develop N application algorithms for these crops that are adapted to Canadian growing conditions and to investigate the performance of these algorithms. In order to develop the algorithms, they have established plots with a wide range of yield potentials through the manipulation of N rates and seeding rates in canola, and N rates in wheat. Seeding rates have been included for the canola trials because canola plants tend to compensate well for low plant densities through increased branching during their reproductive stage. Their main concern is that early season sensor measurements may underestimate the grain yield potential of the crop because of their unique ability. I would suggest that in South Australia we should also include seeding rates into the wheat plots because our wheats have an ability to compensate through tillering and the correct tillering canopy should be determined. The NDVI values of each of these plots are being measured frequently throughout the growing season and this information will then be related back to actual grain yield of the plots. Collecting this data throughout the entire growing season will enable us to determine the crop's growth stage where the yield potential can be accurately determined and where a yield response to N fertilization will still be achievable. This will be the optimum stage for top-dressing N. Currently, they are recommending top-dressing at the 5-6 leaf stage for spring wheat and just prior to bolting for canola. These trials are being conducted at Indian Head, Swift Current, Scott, Brandon and Ottawa. (Holzapfel, 2005).

To test the earliest versions of the application algorithms they are conducting trials on both small plots and on a field scale. The major strategies that are being evaluated include 100% N at the time of seeding, 67% N at seeding and a fixed top-dress rate of 33%, and 67% N at seeding with the top-dress rate determined using an N-rich strip and early season sensor readings.

The GreenSeeker ® only collects 2 bands of information, and hence is not as good as the Yarra N-Sensor and the Satellites in the information they gain from the crop, but is a lower cost sensor. Each GreenSeeker ® module scans 60cm of information, and takes a pixel of information every second.

N-Tech sells 2 models of GreenSeekers ®.

Greenseeker ® RT 200



Figure 16. The N-Tech, RT 200 with 6 Greenseeker® sensors mounted across a self propelled boomspray in Virginia USA.

This system has 6 sensors that are mounted across the urea boom, or boomspray, to scan

3.6 meters of crop in one pass. It is designed for variable rate application of inputs. As the variable rate applicator moves through the crop, N is applied at different rates according to the canopy status of the crop, derived by the NDVI status of the crop compared to the N-Rich NDVI value, and the algorithm used. Economic benefits are likely to be achieved by either maintaining yields with less nitrogen inputs or increasing yields with the same amount of N by redistributing its placement so that it is only applied to areas where a response is likely. Profits of A\$25/ha to A\$50/ha have been achieved in numerous trials. Winter Wheat crops in Oklahoma can be expected by using this sensor.

When talking to Ted Mayfield and Jim Logg of Ntech about the progression of Management Zone work in Australia and the potential for different Potential Yield Zones in the one paddock, we discussed the potential of having a background layer of Management Zones and using the RT 200 to variably apply nitrogen according to the yield potential set up in the different zones. They were very receptive to the concept and said their software developers were already working on a similar concept, and by next year should have this as part of their software.

GreenSeeker® RT 100

Figure 17. The N-Tech RT 100 being used to measure a N-Rich strip in Oklahoma, USA.

This model is for working out a standard rate for each paddock or zone, and is used for scanning the N-Rich strip and a representative area of the paddock or zone. At the end of the scanning, the software works out a nitrogen recommendation for that paddock or zone.

I believe that this has real potential for Australia, especially in the high rainfall zones where the season is more secure, and a spring shut off is less likely to affect the end yield result, but I do have hesitations about finding a algorithm that is able to deal with this in medium to low rainfall zones.

The RT 100 retails for A\$4630 and with returns in the order of A\$20/Ha the return on investment should be greater than the RT 200.

Other uses for the RT 100 are to collect and map NDVI data by adding a GPS to the system. I think this will have limited broadacre usage for scanning 60 cm over a 30 m boom does not scan too much of the crop, and will have special variability problems.



Crop Circle ACS-210 Plant Canopy Reflectance sensor



Figure 18. The Crop Circle ACS-210 being used to measure the NDVI in Corn, Nabraska, USA.

This is a new active ground sensor developed by Holland Scientific Inc, at Lincoln, Nebraska USA, and was released in 2004.

The crop circle sensor provides classical vegetative index data as well as basic reflectance information from plant canopies. It, like the GreenSeeker® sensor, has its own light source, but uses a different patented (pending) light source. At this stage it is only a single sensor, that can be used to compare different canopy structures, or for mapping purposes.

The patented (pending) light source technology simultaneously emits visible and near infrared light (NIR) from a single LED light source. The key benefit of this new light source technology is that the area of plant canopy illumination is identical for both visible and the infrared light bands, essential mimicking the special composition of natural light.

Three sensor models are offered providing yellow/NIR, orange/NIR or red/NIR sensing capabilities. Serial data produced by the sensor can be easily captured using a laptop PC, PDA or other data acquisition devices.

The sensor can be configured to output either raw IR and VIS data so that you can examine crop biomass and N status separately, or it can calculate and output several different crop reflectance indexes automatically.

Examples of these are:

- Normalized Difference Vegetative Index (NDVI)
- Wide Dynamic Range Vegetative Index (WDRVI)
- Simple Ratio Index (SRI)
- Infrared band reflectance (RNIR)
- Visible band reflectance (RVIS)

These indexes have been shown by numerous scientific papers to correlate well with canopy size and N status, and the Crop Circle is the only sensor that provides data for individual wavebands.

Essentially the Crop Circle sensor is the same as the GreenSeeker® in what it can do, but at the InfoAg 2005 conference in Springfield, Illinois USA this year Jim Schepers USDA – ARS from the Agronomy and Horticultural Department in the University of Nebraska presented a paper stating that the GreenSeeker® has a restricted field of view between .25" to 24", and its information is mostly gathered at the centre of the

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sensor's path, whereas the Crop Circle's field of view increased with distance and was uniform across the field of view. This is a big plus for the Crop Circle on ground rigs where the height of the sensor will vary with the slope of the ground and crop, varying through rock and roll of the ground rig.

Jim Wilson from Soil Essentials, Scotland has used this sensor and was very happy with it's performance, and hopes to sell them into the UK.

When in the USA I talked to Kyle Holland about the sensor, and he said that the agronomic package is still being developed and hoped to be out soon. They are also working on a multiple sensor module like the GreenSeeker ® RT200, and hoped to have it out later this year, ready for the 2006 cropping season. At the moment a single sensor package sells for A\$3600 so it is less expensive than the GreenSeeker ® RT100.

There are patent problems with it at the moment with there being a potential patent violation with Ntech claiming that Holland Scientific has stolen a few ideas from the GreenSeeker ® when it was in development at Oklahoma State University, and the case is before the courts at the moment.

I see this sensor as an improvement on the GreenSeeker ® but it does not at this stage have the agronomic backing of the GreenSeeker ®, but it holds great promise, if they can get the agronomic package up and running.

An improved vehicle mounted sensor network for estimating tiller density and leaf area index(LAI) of winter wheat. Research done by Paul Miller at Silsoe Research Institute in the UK.

After a three year study into combining three sensors, a ultrasonic sensor for height, a two wave radiometer for NDVI, and a multi-spectral sensor for chlorophyll and other bands, they have been able to come up with a new form of Compound Vegetative Index (CVI). This can predict tiller numbers, and Leaf Area Index (LAI) throughout the growing season, beyond GS32 at, which they say, is better able to predict Biomass than other similar sensor combinations at these later growth stages. (Scotfond and Miller 2005).

This increased accuracy in the later stages of crop development should allow for better timing and rates of the later inputs such as late N, Fungicides, and Plant Growth Regulators (PGR's). Also being a ground sensor, it can be used to monitor changes in biomass under cloudy conditions, which the satellite based systems struggle with.

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The combined sensor is expected to cost about the same as the Yarra N-Sensor, but at this stage it isn't commercial and is up for commercial consideration to further its development.

There was a problem with its design that I could see with it only measuring a bandwidth at a time, and so it would find it hard to measure the height difference across the rows in a controlled traffic system. This would require either more sets of sensors, or a sideways tracking mechanism to overcome this.

3.2 Precision Agriculture – Data Analysis

In precision Agriculture a lot of information can be collected, 5 years of yield maps, and EM survey, Elevation, Satellite Photo, NVDI Scan, to name a few that might make up a dataset on a single paddock, but how do you correlate all of this information into something that makes sense and you can use to make the paddock more profitable?

This is a question that is being asked throughout the world, and everyone has a different answer, but they all agree it has to do with adequate data analysis, to put the information into a single layer of information that the owner can understand.

Most areas in the world are moving down the path into Zonal Management, which is where the Australian researchers out of the Australian Centre for Precision Agriculture (ACPA) have been world leaders, and I have been very fortunate to part of this program.

There was some debate as I toured the world into how much to clean up the data, and smooth or interpolate the data.

Terry Griffin and Jess Lowenberg-DeBoer at Purdue University in Indiana USA, believe that the data should be cleaned up before analysing it, but don't like Interpolated data because they don't want to introduce any more potential errors into the data.

Australian Centre for Precision Agriculture (ACPA)

The ACPA believe in cleaning up the data and then putting the data through the following process:

Relevant Data Layers : Yield, soil conductivity, elevation



Spatial prediction onto a single grid using block kriging



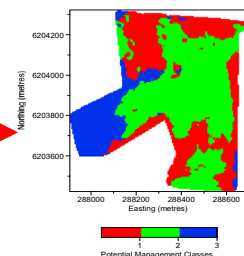
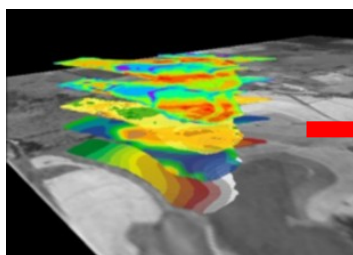
k-means clustering using all relevant layers to delineate production classes



Utilise the mean kriging variance for yield to determine Confidence Interval (C.I.) for class partitioning

(Whelan, 2005)

This gets the data to a point where the data processor, in collaboration with the farmer, can decide on the number of potential management classes, and set out sampling points within each class. The sampling points are very important because they allow the farmer to explore what may be causing the variability seen in the data layers.



Relevant Data Layers
Zones Yield data, EM, Elevation,
NVDI imagery

Data Processing
Home Computer

Management

Figure 19. The Australian Centre for Precision Agriculture's way of determining Management Zones from relevant data layers of a paddock.

Analysis of the soil test should tell if there are any soil amelioration issues that can be dealt with outside of the management zones, and if soil amelioration is needed then it should be done if it is economical to do so. Where there are no amelioration issues, field scale experiments can be established to estimate the response in each identified potential management class to a single input. This single input that is to be experimented on should be determined by the soil test, or if the farmer knows what is driving the variability of the paddocks zones. This experiment should include blocks of marked build-up and depletion of the input, and should include a zero rate block. The size of the block needs to take into account the scale of the farmer's equipment, and spatial constraints due to management class pattern and a desire to minimize area/ financial impact of the experiment. (Whelan, 2005)

Below is the Nitrogen experiment done on canola in 2004 in the paddock Top D on my place at Giles Corner, showing some classic trends seen in using Management Zones.

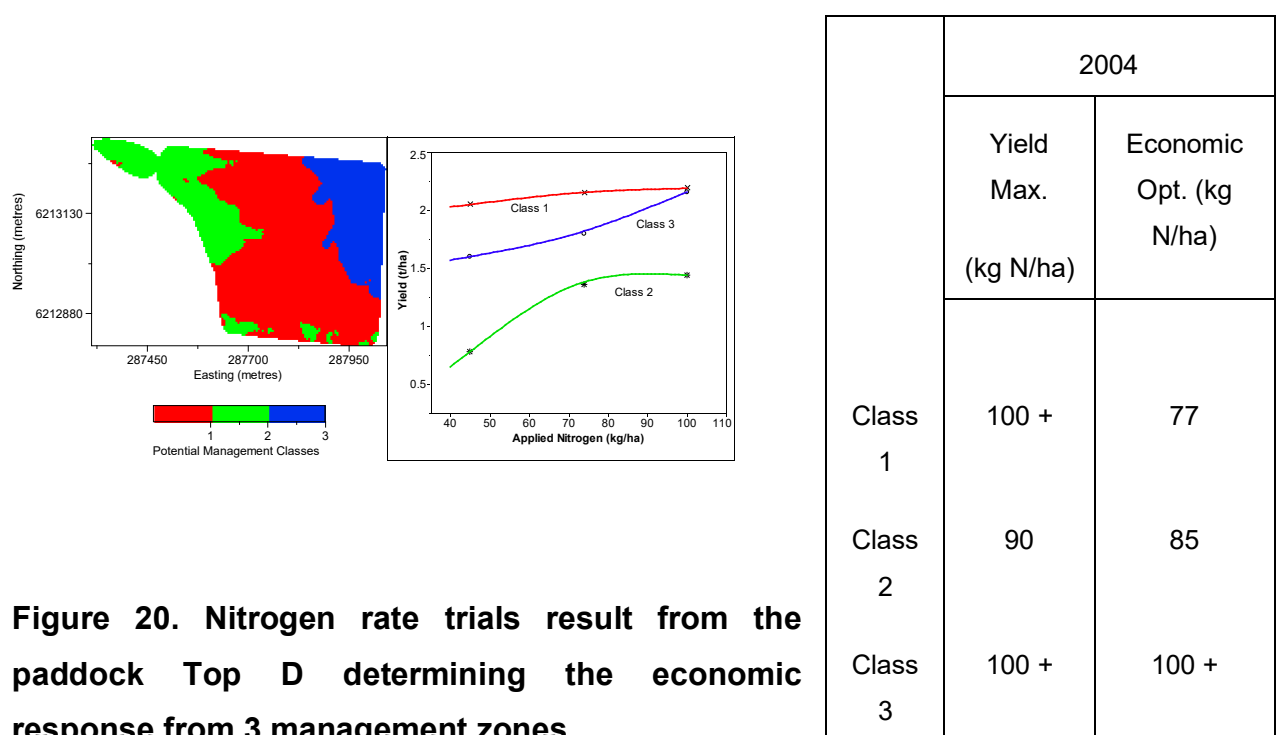


Figure 20. Nitrogen rate trials result from the paddock Top D determining the economic response from 3 management zones.

This is the summary done by Dr Brett Wheelan from the ACPA.

"In TopD the classes respond in terms of total yield over the paddock as 3>1>2. Except in 2003 field peas where 2 outyielded 1. In the soil tests prior to field peas in 2003 the soil nitrate was similar in Class 1 and 2 and one third less in class 3. The field peas yielded 0.7/1.7/2.0 t/ha for classes 1/2/3 respectively. This gave the soil total N prior to

sowing canola in 2004 of 58/84/73 kg N/ha. The better yielding peas had brought the N up in 2 and 3, but it seems here that water must have been playing its part as Class 1 and 3 were well enough supplied with N, class 3 looks like it can use the higher rates of N at the moment.”

The making of management zones is a complicated statistical process and the farmer will either have to do training on the process, ACPA run such courses, or pass the information onto a consultant for them to do the processing of the data. I believe this is one of the major constraints in this process, but the information gained is very impressive, and gives a great foundation to variable rate application of inputs.

Chris Dawson of Chris Dawson Associates suggested that Zonal Management in a paddock is a good idea, but caution needs to be used when putting in Yield Maps, for they can vary greatly according to the type of season the yield maps were produced in. To overcome this Chris suggests that a large database of yield maps be compiled, and each year/spring yield maps be placed in the data analysis of similar years, to the year the farmer is experiencing at the time and the seasonal forecasted finished, into the data analysis process to produce the Management Zones. By doing this the management zone produced should be more accurate for the season the farmer is experiencing, and should overcome the flip year syndrome on yield maps in contrasting years. The downside of this is that you will need a large database of years in order for this to work, and return on investment would be very slow.

Another idea along similar lines is the need for better weather forecasting to make management decisions easier when dealing with fertiliser and fungicide requirements.

SST

When in Oklahoma, I saw the agricultural software firm SST. SST produce open ended Geographic Information System (GIS) software which can be used to comprehensively analyse layers of paddock data, and has excellent statistical analytical tools which can be used to create Management Zones, and query information for better management decision-making.

This GIS software is called SST Toolbox® and the full version is designed for crop consultants, fertiliser/chemical dealers, educators, researchers and farm managers. It is able to analyse data to show, within-field variability, regression curves, correlation matrixes, cross-classification, net income analysis and lots more. It processes yield data in numerous forms. It creates fertility recommendations from soil tests, and removal.

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It can be used to compare between datasets, paddocks, farm, different farms, and different farmers. It is very expensive software, at A\$6666.00, but is excellent in its data analysis, and would be ideal for a consultant to work in Precision Agriculture data analysis.

They also sell SST Toolbox Lite®, which has no statistics and is designed to make fertiliser and chemical recommendations, including VRT recommendations.

The last GIS software sold is SST Toolkit® which is designed for the farmer. It is designed for simple GIS work who have access to the SST Toolbox ® through a local input supplier or crop consultant. This costs A\$2320.00.

They also sell SST Straus ® which is a Pocket PC based program which with a GPS can be used in paddock record keeping and paddock scouting.

SST also offer on-line data analysis at approximately A\$1.00/acre/season.

SOYL in the UK offer training days on yield map interpretation called “SmartYield plus” . “SmartYields Plus” is a service which involves a series of bulletins and group training to help guide the farmer through a simple, structured method of looking at their yield maps.

Topics covered include:

1. Being confident of your data – Recognising errors.
2. Choosing a field for investigation – Yield variation.
3. Interpreting Maps – Field Investigation.
4. Interpreting Maps – Trends over Time and Management Zones.
5. Trials – Using yield maps to assess management options.
6. Combining guidelines.

John Deere see a large potential in new software to analyse yield maps and take the data further to the profit of the farmer, and were developing software to do this.

3.3 Precision Agriculture - What do you vary?

The list of inputs is unlimited, it depends upon whether you will get a financial gain by varying a particular input in a paddock.

In the UK and USA they look to even up a field with their inputs and hence they are looking at varying seeding rates to get an even establishment, they look at varying fertiliser inputs to even up the crop, and use Plant Growth Regulators, and fungicides to even up the crop.

In Australia under the use of Management Zones, we are looking at varying our inputs according to the yield potential of the zone, so we vary our inputs in order to optimise the input in each zone. This might include different plant populations in each zone, i.e. different seeding rates, different fertilizer inputs according to different removal rates from the previous history, and different yield expectations. Also with resistant weeds occurring in patches the idea of increasing seeding rates to out-compete resistant weeds are being experimented with successfully at the moment.

3.4 Precision Agriculture - Disease Management.

In research done by John Heap and Allan MaKay of the South Australian Research and Development Institute, field studies have demonstrated a correlation between soilborne disease inoculum levels and different management zones. With this information there may be a way of improving soil sampling for soil diseases, and if positive, has the potential to reduce the cost, risks and losses, by targeting pesticides and cultural control to the zones affected. Also the economics between the zones might be different, with a potentially high yielding zone more economical with a higher rate of pesticide than a lower yielding zone. (Heap and MaKay, 2005)

It has also been found in the same study that there is 2 to 5 times less root disease on the inter-row than the seed row, and hence where root disease levels are expected to be high it would be beneficial to sow in-between the rows, i.e. inter-row sowing, to reduce the effect of the root disease on yield.

3.5 Precision Agriculture - On Farm Trials

This is one of the real benefits of having a yield monitor. Jim Wilson of Scotland he agrees with me, and runs extensive input trials across his farm.

By placing input trials in a single zone, and having a yield monitor to harvest them to collect the potential yield differences, the farmer has the ability to run input trials to fine tune their farming system on their soil in their environment. When you use traditional statistical methods in analysing the data, one must either place the comparative trial in a single management zone where the environment background is kept to a minimum, or put blocks across the paddock to even up the background environment.

Terry Griffin and Jason Brown from Purdue University in Indiana, USA, have a different method of running on-farm trials. They believe that the traditional method of minimising the background noise, and using traditional analytical methods is not the best way of running on-farm trials because they have the assumption that all treatments operate independently from each other, and clearly they do not. They are working on putting large non-intrusive treatments across all paddock zones, and using spatial analysis to analyse the data. Spatial analysis methodology assumes that all treatments are related to each other and hence is a lot better method of analysing yield data because of the connection with the environment.

SST use their SST Toolbox® program to compare varieties and other inputs on a whole paddock level. To do this you need a very large database in which they have. They have their USA clients give them the data and they put this through their software and share this information to those who have paid for this service. A similar program runs out of Purdue University.

Opti-Crop from Kentucky USA run extensive trials in the Opti-Crop business, but they encourage their farmers who have yield monitors to run properly constructed trials on their own properties.

3.6 Precision Agriculture - Farm Equipment.

While on tour I came across lots of different types of farming equipment. A lot of it is not applicable for Australian broadacre cropping, but there was some machinery and issues that Australian farmers could learn from.

3.6.1 Soil Preparation Equipment.

There was a lot of soil preparation equipment used overseas, and I am of the strong belief that even though their extensive working of their soil might create a soil structure that maximises yield, long term they are doing a lot of damage to their soil, and it is making their farming not profitable in a lot of cases.

One piece of equipment that might have a place in Australia is the use of sub-soilers in badly compacted soil. I saw them used in New Zealand, UK, Canada and USA. Sub-Soilers are deep tined implements, which work deep in the soil, lifting the soil and shattering the compaction in the soil. A problem with them is that they use a lot of horsepower to pull, and working with them is very slow.

In Australia, I could see them being used in badly compacted soils, under a controlled traffic system. They would be used during the Summer/Autumn period.

A good example of this type of equipment is the CASE IH Ecolo-til® 2500 which uses tiger® Points, which have wings that sweep downward, rearward and outward. This design creates a “lift, twist and roll” action that shatters compaction, and reorients soil particles.



Figure 21. The CASE IH Ecolo-til ® 2500 seen at a dealers yard in Saskatchewan, Canada.

3.6.2 Sowing Equipment.

There are a lot of different ways to sow a crop, but I am going to concentrate on the direct drill sowing equipment because this is the best equipment to sow a crop in Australian conditions.

Tined vs. Disk

When talking to manufacturers, consultants, and researchers throughout the world the verdict is split, and it depends on what system you are in as to what planting system you take on. All the consultants and researchers in the USA who were advocating conservation agriculture were pushing disc machines as the best way to sow a crop. There is no doubt that for soil conservation measures, seed depth control, the ability to cover the ground very quickly, and the ability to sow in heavy stubbles discs do the job, but under the Australian conditions of minimal stubble breakdown before sowing leading to pinning, dusty conditions leading to high maintenance costs of bearings, and the root disease *Rhizoctonia* causing problems, I am yet to be convinced of their benefit in Australian conditions. Dwane Beck of Dakota Lakes Research Centre is adamant that disc machines are the only way to sow, but Phil Needham of Opti-Crop suggests that we need to get rid of our *Rhizoctonia* problem before using a disc machine, for in the USA and Canada they have a winter freeze in their soil, which kills this fungus. In Canada they have mostly adopted tined machines because of their ability to sow in wetter conditions, which is very important because they are waiting for their soils to dry out from their winter freeze before starting to sow.

Variable Rate Equipment.

There were numerous methods of variable rate sowing with each having their own strengths and weaknesses.

Electric Drives.

This method is an electric drives which speeds up, or slows down, a measuring wheel for granular inputs, and flow meter for liquids. It has a strength in it is a simple accurate way of measuring and changing the flow of inputs, but it can be slow to change especially if changing large amounts. It also has a limit as to the ratio of which the change can be. It is used on airseeders for granular inputs, and boomsprays for liquids. Another disadvantage to this system is that if the electronic system breaks down, it can be difficult to change the rate if an override switch is not installed on the metering device.

Actuators.

This method is used on granular equipment, which uses a hydraulic ram to move a lever that changes the metering mechanism on a gear box. It has an advantage in the rate can be changed quickly once the actuator remembers its position over a range of rates, but it can be hard to get an exact rate, especially if parts start to wear over extended use. It is easy to override, so if the electronics break down, manual changing of rates is easy.

Gates

This method uses a hydraulic ram to raise or lower a metering gate. Its advantages are that it is a cheap method, and that it can be quick to change the rate, but gates are hard to get an accurate rate, so varying it can also be difficult as well.

3.6.3 Spraying Equipment.

With GPS units becoming popular to use on spraying equipment, not only has this been used for guidance, it is also being used to variable rate liquid inputs, and is being used for Auto Boom Section Cutoff (ABSC).

Auto Boom Section Cutoff (ABSC) systems are becoming popular and range from automatically cutting off existing boom sections, to cutting off every nozzle. They work on the principle that the computer working the spraying system counts in front, the seconds coming into a previously sprayed line, with the GPS being used to tell where the previously sprayed line is, and once the sprayer section or nozzle reaches that predetermined time, the section/nozzle turns off, making a very accurately sprayed paddock with very little double spraying/misses on the ends.

Clay Mitchell, of Mitchell farms Iowa, USA, has developed an “RTK Nozzle Controller” with collaboration with KEE Technologies and NAVCOM. It is an ABSC system, which uses RTK guidance to cut-off every nozzle with RTK accuracy. It is the ultimate in spraying accuracy, and he estimates that this system increases the sprayer efficiency by 30% and decreases chemical usage by 20%. It was born out of having to spray around waterways and allows Clay to work and spray across a predefined waterways with the controlled traffic lines running through them on an angle.

Throughout the world spraying UAN nitrogen fertiliser using stream bars or stream nozzles is seen as a very desirable method of applying late nitrogen, for not only can you use existing controlled traffic of in-season tramlines to minimise crop damage, but variable rate nitrogen is a possibility with the flow meter changing the rate on the go, and the spread of nitrogen is very accurate, but caution needs to be heeded in windy conditions that the stream is not broken which would enhance the chance of crop damage.

3.6.4 Spreaders.

Lots of different methods for spreading inputs are used worldwide.

Fertiliser Booms.

These were very popular in the USA and Canada, with large contracting trucks with enormous fans driving at very quick speeds, spreading large quantities of fertilisers very accurately, but for variable rate spreading I think they would struggle with the very large flow of fertiliser being difficult to change the rate quickly enough. They have a large advantage over other spreading methods in that they can be used in most environmental conditions, especially in windy conditions where disc spreaders struggle.

Figure 22. A Contractors Fertiliser Boom Truck seen in Brandon, Saskatchewan, Canada.



Disk Spreaders

These are used extensively in Europe and are very good at variable rate spreading. They are relatively cheap, but you get what you pay for, especially in the accuracy in the spread of the material. The more expensive spreaders spread well in ideal conditions especially in light wind conditions, but don't spread well when the wind rises above 15 knots.

3.6.5 Yield Monitor Equipment.

While in the USA I visited both Case IH and John Deere and discussed their yield monitor equipment.

Case IH use the Advanced Farming System (AFS) to yield monitor. It is very accurate and uses Ag. Leaders components. There are no new components this year, 2005, but in the next year or two they will have a new Universal Display, and are trying to be ISOBUS compliant by 2008. As stated previously there is a software update that will allow for RTK recording of Elevation while you are harvesting and logging yield.

John Deere has a new console out this year, coming in two versions, a 21 centimetre, and 26-centimetre display. Both of these are fully colour screens, with the GSD 2100 being the smaller screen, have a display controller mounted next to the screen, and the larger GSD 2600 is a touch-screen that is very easy to read even in direct sunlight. Both consoles come with pre-loaded GreenStar ® Software that allows for Manual Guidance, Paddock documentation, and Map Based Prescription, used to variable rate inputs. There is upgrade software available to enhance the functionality of the consoles. The new software allows for the John Deere RTK system to log RTK elevation.

John Deere was striving towards CANBUS compliance but was not moving quickly on this.

3.6.6 Stubble Management Systems.

When moving into a controlled traffic, no-till system the accurate spread of stubbles becomes very important for this is the next source of organic material to be broken down and converted to nutrients. If you spread this stubble unevenly then some of the soil will have more organic material than others, and if this is repeated over a number of years then some rows will have ample organic material in the soil, and others will be deficient.

When talking with a number of growers and advisers in the USA, all commented on the importance of good stubble spreading, and most have a conversion on their harvesters to get a good even spread. Phil Needham says Opti-Crop sell their grower's conversions to growers to improve the spread in their system. These conversions are different for different harvesters, but generally they recommend choppers, fans to blow the stubble out the back of the harvester, and a good spinner to spread the heavier straw out the full width of the harvester's cut.

In Europe the good growers mostly use Class harvesters (CAT in Australia) because of the excellent spreader on it that chops the stubble up very fine, and throws the material evenly to the full width of the cut.

The recommended height to cut the stubble when you are sowing with a tined machine is just less than the row spacing of the sowing implement, but keep the stubble longer if you are using a disc machine to sow with.

4. Controlled Traffic Systems.

Interest in Controlled Traffic is growing throughout the world with schools conducted in UK, and USA while I was there. Australia is seen as world leaders in this work, and so I am referring to information gained while adopting this technology on my farm in South Australia.

Controlled traffic is all about matching the wheel widths of the tractors and farm equipment and the operating widths of the farm equipment. The farm equipment should be multiples of either 1, 2 or 3 times the sowing equipment so all wheeled traffic can be confined to either permanent wheel tracks, known as Controlled Traffic systems, for a single season, known as Tramline farming. The harvester can be in, or out of the system, and it is up to the individual farmer whether they consider that the harvester is causing enough compaction to warrant being in the system, and that will depend upon the expected soil conditions at harvest time.

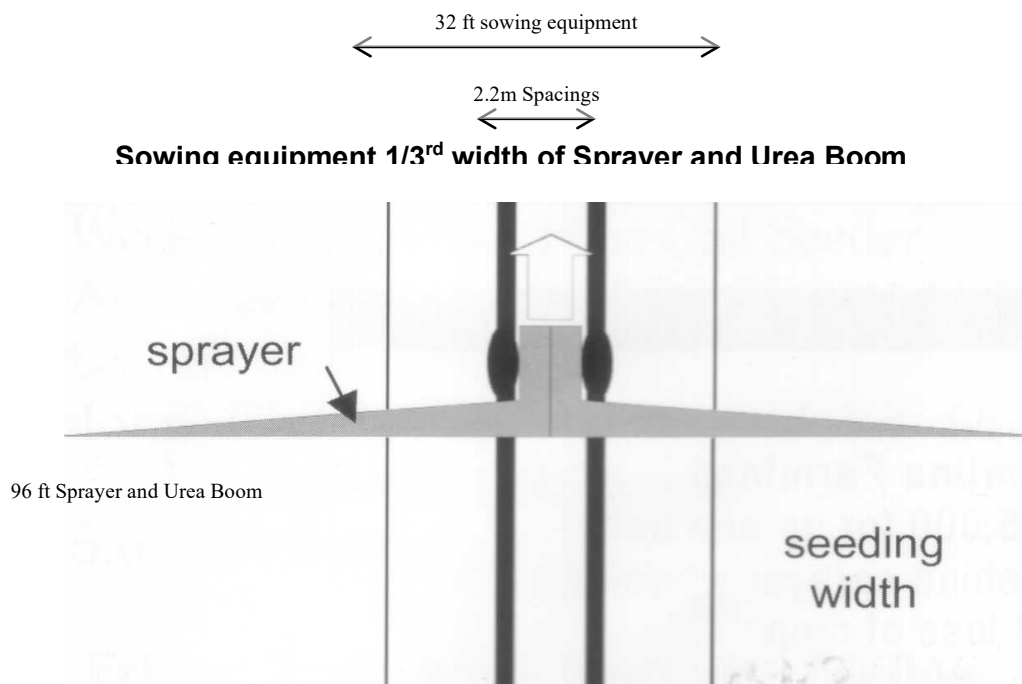


Figure 23. The controlled traffic set-up at my farm in South Australia.

Traditionally tramlines have been kept bare, and overseas they are unsown, but with the problem of herbicide resistant weeds, and potential erosion problems in Australia, other tramline methods have been developed.

These different methods include bare tramlines, fuzzy tramlines, and sown tramlines.

1. **Bare tramlines.** Bare tramlines are tramlines that have not been sown, and can be made by removing the sowing tine, or by pushing two tines apart to leave a large row space. These tramlines provide a very firm compacted zone for the machinery to run on. There is no crop damage during the post-seeding operation, and they are very visible for in-crop guidance. The plants on either side of the row compensate in yield through accessing the extra water and sunlight and the overall benefit more than compensates for the area lost to bare wheel tracks. Opti-Crop in the USA advocate diverting the seed and fertiliser from the missing row into the two rows either side. To do this they sell an electronic set-up, which counts the number of rows, and on the controlled traffic row, through a set of solenoids, diverts the seed and fertiliser into the rows alongside.

Figure 24. A Airtram controlled traffic seed and fertiliser diverter used by Opti-Crop, USA.



- 3 **Fuzzy tramlines.** Fuzzy tramlines are made by taking out a tine out where the wheeled traffic is meant to go, and running the seed out in front of the sowing box tyre which pushes the seed into the ground at a shallow depth. These tramlines provide some in crop guidance and compete against any weeds germinating in the tramline, but there are problems with trifluralin being incorporated properly in this system.
- 4 **Sown tramlines.** Sown tramlines are made by sowing the row normally, or on a modified tine, so the seed is put at a depth, and the trifluralin is incorporated by the soil throw. A sown tramline is often difficult to distinguish from the rest of the crop, and usually requires an Autosteer tractor to operate correctly. I have adopted this system for the first few years to allow the tramline to firm up, making it undesirable for the crops to grow before moving to the bare tramline system.

To operate a controlled traffic system effectively, a guidance system is recommended which may be mechanical, such as marker arms, or electronic, such as video or global positioning systems (GPS) for more accurate driving to minimise overlap and to set up and maintain the controlled traffic lines. These lines can be on curves, or up and back. Curved lines may lead to wider tracks for towed machinery lags behind the tractor, and unless the farmer is using tractor mounted sprayers and spreaders, specialised steered trailing boomspray or spreaders, or a self propelled 4 wheel steering equipment then up and back traffic lines are recommended. While in England I saw many trailing boomsprays fitted with hydraulics, which were making the trailing equipment following the wheeltracks of the tractor. This was done by either two hydraulic rams on the tow bar pushing the towing equipment into the correct position, or the wheels on the towing equipment turning like a car axil, to follow the tractors wheel marks.

Accurate driving and matching machinery operational widths are complimentary to precision farming with the same GPS equipment being able to be used for variable rate applications of fertilisers and herbicides.

Table 3. Guidance Systems, approximate costs and accuracy's, as at October 2005.

Guidance method	Approximate \$	Accuracy (long term)	Accuracy (pass to pass)
Camera	1500-2000	50cm	50cm
Permanent wheel tracks	5-10/ha	30cm	30cm
Marker Arms	1000-12,000	30cm	30cm
Visual GPS guidance (Light BAR / screen)	10000	1 m	30cm
Sub-metre Auto-steer (Satelite / Marine beacon)	21000	1 m	10-15 cm
10cm Auto-steer (Satelite Omnistar HP)	31000	10 cm	5 cm
RTK 2cm Auto-steer (Base Station on farm)	50000	2 cm	2 cm

As you can see from table 3 there are different ways of providing guidance for a controlled traffic system, it depends on how accurate you want to get in the short term and long term, and basically you pay for what you get. Each farmer needs to decide the level of accuracy they need to operate on, depending on the layout of the farm, the size of the farm, whether the guidance is going to be used for more than basic guidance, and of course cost of putting the guidance on the machinery.

When adopting a controlled traffic system the gains are more than just increasing yields by reducing compaction, and it depends upon the guidance accuracy as to what benefit you can achieve.

The benefits include reducing input costs by between 3 to 10% from less overlap through more accurate driving, easier driving from using a guidance system, and when you include Autosteer, the driver is much less fatigued. The compacted tramlines also allow for earlier access for operations such as seeding, spreading and spraying in wet conditions, and allow for nighttime spraying important for areas where daytime windy conditions occur. Also controlled traffic systems are estimated to reduce fuel use by up to 25%. Fuel and fertiliser savings alone could translate to 200 tonnes of greenhouse gas abated for each tonne of improved grain production. (Webb et al, 2004).

The more expensive Real Time Kinetic (RTK) guidance, where repeatable 2cm accuracy is achieved, allows a suite of agronomic opportunities that are not available at the lower levels of accuracy.

These include the ability to sow in-between stubbles, which in cereal stubbles according to John Heap of the South Australian Research and Development Institute can increase the second cereal yield by achieving 2 to 5 times less root disease, improves the efficacy of soil applied herbicides, and increases the stubble handling of the sowing equipment.

Another advantage of the RTK system is allowing the use of inner-row shielded sprayers. These inner-row shields enable the use of non-selective herbicides between crops to improve weed control, and require very accurate driving to stop the spraying of the crop.

The use of band spraying is another opportunity with fungicides targeting the crop only, saving the cost of fungicides hitting the ground. This is particularly useful in crops with low biomass like chickpeas, or where a fungicide is required early in the crops development before canopy closure.

A problem with all of the above opportunities is that even though the tractor is driving to an accuracy of 2cm the trailing implement may creep, especially if the land is sloping, plus a tillage implement tends to move into a path of least resistance, making it difficult to sow inner rows.

There are three ways of overcoming this problem;

1. Using a three point linkage connection set-up on the seeding bar, reducing the side movement of the bar. Clay Mitchell of Mitchell farms IOWA, USA, uses this system to plant directly over pre-applied nitrogen.
2. Connect using the three-point linkage system and then use a hydraulic side shifting mechanism to manually or automatically shift the implement to the position of choice. The Robocrop ® system developed out of Silsoe Research institute in the UK uses this type of technology. This is a product, which uses a camera set up on the bar of the tillage implement, looking 2.5m in front, identifying where the crop rows are and by using a hydraulic side shift mechanism, guides the tillage between the rows. This cultivates the weeds between the rows and leaves the crop standing. It has been commercialised by Garford farm machinery and Silsoe Research Institute. It is only able to identify green crop rows and so the technology as it is standing will only work after the crop is up. So, Inner-row cultivation or fertilisation is the only possibilities at the moment. I had discussions with the developer, Nick Tillett, about the possibility of attempting to identify stubble rows for inner row and he said that this was difficult and can't be done at the moment, but if a commercial partner were to be found he could research this further.
3. Put two hydraulic rams on the A frame to pull the implement up and square to the tractor. Jim Halford of Conservapak showed me this system. They use a short A frame on their bar, and attach large hydraulic rams as an extra which not only is able to pull the bar up the hill, but also pulls the bar back into square, important when dealing with inner-row sowing.

5. High Input Cropping.

Growing a 10T/ha crop of wheat is an art form, with not only lots of rain and cool conditions necessary during grain-fill, but also the right timing and rates of fertilisers, plant growth regulators and other inputs are needed in order to maximize yield. In the UK and USA they had such an environment and their farmers, plant breeders, and advisers shared their experiences with me on how to maximize yield. When chasing maximum yield, you need to remember that costs can easily run away from you and you might produce a 10t/ha crop at a loss.

5.1 The UK.

5.1.1 Peter Riley of the Arable Group (TAG)

When in the UK I spoke to the agronomist, Peter Riley of The Arable Group (TAG), which operates out of the old Morley Research Institute. Peter runs a large consulting firm with 12 agronomists working under him, covering 90,000 Ha and 224 farms.

Research is done at the Morley farm funded by a farm membership base, donations, and the, HGCA and they do a little contract research for industry. Crops covered under its research include: Winter and Spring Wheat, Winter and Spring Barley, Winter and Spring Beans, Sugar beat, Potatoes, Rape, and Spring Peas.

Ploughing and seedbed preparation is the norm although minimum tillage is being trialed and practiced. The seeding generally is done with accurate disk seeders that require a lot of horsepower because they do a lot of soil movement in one pass to get a good seedbed. It was not common to see a 300hp tractor pulling a 16-foot seeding drill. Press tires are used to get a good seed/soil contact.

Growing winter wheats.

Seeding rates:

The seeding rates vary according to seed size, and, more importantly, the sowing date, with lower rates being used in earlier time of sowing, i.e. 75 kg/ha and up to 175 kg/ha for late sowing. (Seed size is very large when compared to Australian varieties.) The aim of this is to create an environment where they will be able to control the tillering of the crop with Nitrogen management. They have seen research in dealing with resistant weeds and under those conditions the sowing rate would not be dropped below 120kg/ha.

No fertiliser is applied with the seed, and they do not apply Phosphorus based fertilisers.

Nitrogen Management:

The rate of Nitrogen was formulated using agronomist and farmer experience and by looking at response curves.

As a general rule no Nitrogen was applied at sowing time because of the Nitrogen available to the wheat seedlings from the mineralisation caused by the seedbed preparation.

	1 st Application	2 nd Application	3 rd Application	4 th Application
GS	GS 25	GS 31	GS 33	GS 37
Crop %	20%	40%	40%	Only if Needed
For 10T/ha	40kg N	90Kg N	90kg N	40kg N

The timing of the first application didn't matter, and it was only used if the crop needed a boost to its tiller number.

They have conducted experiments comparing the use of Urea to other sources of liquid N products at GS 37 and have come to the conclusion that there are no significant differences between them, therefore the loss of Urea is not as high as first thought.

Growth Regulators:

Peter considers that the use of growth regulators has been a significant step in increasing yield at very low cost.

The Growth Regulator program is as follows.

	GS 30/31	32	39
Lodging Risk			
Low	CCC 2.25		
Low/Med	CCC 2.25	CCC 1.0	
Med	CCC 2.25	CCC 1.0	Terpal 1.0
High	CCC 2.25	CCC 1.0 + Moddus 0.1	Terpal 1.0

CCC = Chlormequat

The timing here is done to suit the fungicide program, with the CCC timing best done at GS 30 and then GS 31.

Fungicide Program: (Aimed at controlling *Septoria tritici*)

The aim of the program is to protect the leaves from the 3rd leaf onwards.

Timing	Name	GS
T1	32	(3 rd leaf emergence)
T2	39	(Most important spray if little disease present)
T3	Ear Emergence (Probably with Strobilurin + Epoxiconazole)	

Insect Control

To control BYDV they have a 3 spray program with the aphids not being active during the winter period for it is too cold then.

They use 0.2L/Ha of Cypermethrin.

- 1st spray 14 days after Crop Emergence.
- 2nd spray 6 weeks after Crop Emergence.
- 3rd spray At ear emergence.

Conclusion:

The expected field program is as follows.

1. Soil Preparation
2. Crop Sown.
3. Spray insecticide 2 weeks after crop emergence for aphid control.
4. Spray insecticide and herbicide 6 weeks after crop emergence.
5. At GS 25 Spread N with 40kg/ha N if needed.
6. At GS 31 Spray Chlormequat Growth Regulator and Herbicide for Wild Oat control.
7. At GS 31 Spread N with 90kg/ha N.
8. At GS 32 Spray T1 Fungicide and Chlormequat if crop growth is good.
9. At GS 33 Spread N with 90kg/ha N.
10. At GS 37 Spread N with 40kg/ha N if Bread Wheat crop for extra protein.
11. At GS 39 Spray T2 Fungicide plus Turpell Growth Regulator.
12. At ear emergence apply T3 Fungicide plus an insecticide for aphid control.

Peter said the aim was to produce a 10t/ha+ crop and his clients would be disappointed if this was not achieved. This program costs a lot of money and the end result showed there is little profit margin in it, and most times it is done at a loss. With the change of the subsidy program in the UK to Whole Farm Payments, they will need to be optimising yield not maximising yield.

5.1.2 Simon Francis for CPB Twyford.

Simon Francis works for CPB Twyford, a large breeding company in England. Simon is the agronomist in the company and works extensively on getting the most out of their varieties, through correct fertiliser rates and application timings. The aims of the breeding program and fertiliser recommendations are: producing an open canopy with low disease and lodging risk by better air movement through the canopy, better sunlight penetration onto the lower leaves and more efficient nutrient use. In the breeding program this is achieved by breeding for smaller erect flag leaves, and stiff straw. They recommend the use of nitrogen (or not) prior to stem extension to manipulate tiller numbers, and most of the nitrogen goes on after this to feed yield and quality at flag leaf.

Nitrogen.

Their philosophy on canopy management is to set an objective on the number of ears you want to achieve at the end of the year and work backwards. In England in spring wheat (the closest to our varieties) they are aiming for 450 to 600 ears/square metre. After tiller dieback you need to have around 600 to 700 tillers/square metre. To achieve this they are aiming to produce 3 tillers/plant, so they need to establish 200 plants/square metre.

In working through an Australian 5t/ha wheat crop nitrogen equation, the theory would be:

$$\begin{array}{rcl} 5\text{t/ha wheat at } 12.5\% \text{ Protein} & = & 125\text{N/ha Crop N.} \\ @ 30\% \text{ uptake efficiency} + 40\text{N} & = & \underline{40\text{N/ha}} \\ & & 165\text{N/ha} \\ \text{if Soil N is } 60\text{N} & & \underline{-60\text{N/ha}} \\ \text{Total N} & = & 105\text{N/ha in theory.} \end{array}$$

- Apply 40kg/ha N at tillering, if need, to promote tiller numbers to get to the target tiller number. This could be 500 to 600 tillers/square meter in Australia.
- At GS 31/32 add 60N/ha.
- At GS 37 add the balance.

Fungicides.

Simon recommends a good Triazole spray at GS 31/32 for septoria, and a Strobilurin + Triazole spray at GS 39 (Flag Emergence).

Growth Regulators.

Simon recommends the use of Cyclosol at GS31, and the canopy needs to be monitored for growth for further applications of Cyclosol or Modus.

5.2 The USA.

5.2.1 Phil Needham for Opti-Crop.

Phil Needham, an agronomist for Opti-Crop, ran me through their program for producing high yielding crops out of Indiana USA.

They work on the principle of a systems approach with good soils leading to good yields, and are pushing the use of No-Till and Controlled Traffic as a way of achieving high yields and profits.

On the agronomy front, Phil suggests that high yielding crops start with quality seed. All seed is graded heavily over a large 2.5mm sieve, or better a gravity table. It is treated with a fungicide pickle and they ensure that all seeds are evenly treated. They do a germination test on all seed to be sown to work out the amounts of live seed.

The sowing rates that they recommend depend on the field conditions at the time of sowing, and the time of the sowing, with early good conditions being sown at 350 live seeds per square yard to 450+ live seeds/square yard in late poor conditions. They then weigh the seeds to work out how many seeds per pound, and use this to calculate the seeding rate in pounds per acre.

Variety selection is of vital importance. Opti-Crop does extensive testing of varieties, for there are a lot to choose from in the USA. They recommend their growers to look at their company's trials and to trial 2 new varieties each year against the grower's existing lines.

As stated previously, residue management is of vital importance with an even spread of residue needed for seedbed preparation.

They extensively grid sample all paddocks prior to sowing to determine the amount of nitrogen at a depth in the soil, plus other nutrients like Phosphorus and other vital nutrients.

The sowing of the crop should be done with good equipment that is able to sow the seed at a good, even depth. Disk Machines are recommended for this. The Machines should be checked out prior to sowing to ensure that the metering mechanisms are operating correctly, the tubes are not worn through, the springs on the tines or disks are at the correct tension, and the tyre pressures are correct for correct placement of the seed. The seeding process should be thought of as moisture management, with low soil disturbance not drying the soil out during the seeding process, and a good even cover of stubble left after sowing to hold the moisture in.

Nitrogen management is about tiller management. They are aiming for 600 to 650 ears/square metre. To achieve this they are aiming for 800 to 1000 shoots/square metre.

At sowing they apply 20 to 30kg/ha N for early plant health.

At GS 25 they look at the health of the plant and plant population. If there are 200 plants or less established they apply 50 to 75kg/ha. If there are 300 plants/square metre or more they apply only 30 to 40kg/ha of N.

At GS 31 they apply the balance of their nitrogen requirements, which is in the order of 50 to 75kg/ha of N.

At the Mid Milk stage of the crop they would apply foliar urea for protein on their hard wheat.

They have a harsher environment than in the UK and hence are looking to maximise the number of spikelets in the head, which is done by ensuring that the plant is not lacking nitrogen prior to GS 31. There is a balancing act between controlling tillering and ensuring spikelet numbers are maximised, which would be the case in Australia as well.

Phosphorus management is done through soil testing and is applied all at sowing so they are using the products DAP or MAP at sowing for nitrogen and phosphorus requirements.

They are strong advocates of ensuring that no nutrients fall short, and are in balance.

When the crop is growing Simon was recommending the control of Barley Yellow Dwarf Virus (BYDV) by constantly spraying the crop with insecticides to control Aphids.

When looking at diseases Phil was recommending the use of fungicides at GS 30 and at Flowering if diseases are present.

They don't use Plant Growth Regulators in their program because Chlormequat banned in the USA.

Conclusion

Congratulations Australia, we are world leaders in most aspects of Conservation Agriculture and Precision Agriculture, but this should not stop Australian agriculture moving forward and staying ahead of the world in these technologies. Australian farmers need to be world leaders in optimising profits to stay competitive against grain exporting nations production because we operate under a system of very little Government support.

The Australian environment being a relatively dry environment, when compared to the UK and USA grain growing regions, gives us a significant advantage in that we don't have the same nutrient pollution problem as these regions and so the public pressure is not on the Australian farmer, at this stage, to clean up polluted waterways. But the Australian farming environment is still prone to wind and water erosion, and everything should be done to protect our soils and ensure that the vital resource, is kept in a healthy and productive state for our economic benefit. Even though the public pressure is not on the Australian farmer to the same extent as overseas, we should still keep in mind what is happening overseas so public pressure does not fall heavily on us in the future. The Nutrient Management Plans and other bookkeeping methods being enforced by overseas governments on their farmers are making the business of farming very expensive, and should be avoided at all costs. Rather, a voluntary scheme should be entered into to ensure traceability so that our foodstuffs can be labelled "Clean and Green".

In order for the Australian grain farmer to stay ahead of the rest of the world we need to adopt new technologies such as Carbon Farming, Controlled Traffic, and Precision Agricultural techniques to improve our soils, and become efficient farmers of water with the least amounts of inputs. There are numerous new techniques and tools being developed worldwide, and it is up to the funding bodies to research theses for use in the Australian environment to help improve our profit margins. Of particular note are the remote sensing techniques that are being developed overseas that potentially could help optimise inputs and other management decisions. I believe the Farmstar®, Greenseeker ® and potentially Crop Circle®, have futures in the remote sensing of the crop for Nitrogen, Fungicide and potentially Plant Growth Regulator inputs. The new on-the-go sensors for EC and pH soil mapping, and grain Protein mapping also have a future in Australia.

The use of Management Zones has a place in identifying areas of different yield targets, and will be used in conjunction with these other techniques especially when applying nutrient balancing theories.

Nitrogen Budgeting has a problem in working out the amount of Nitrogen that is leaving the soil through mineralization, but the N-Rich strip being advertised by N-tech and the RT100 Greenseeker ® has potential, as well as the Plant Root Simulation Probe (PRS) from Western Ag. Innovations Inc. from Saskatoon, Canada.

I think the best way of applying Phosphorus is to replace that taken from the paddock in the grain of the previous year's crop. To do this a variable rate map should be produced from the previous year's yield map, and the amount of Phosphorus lost in grain yield calculated.

An economics summary of some of the new cropping tools is as follows:

Zonal Management	up to A\$50/ha
Farmstar ® UK	A\$55/ha GM, 1/3 rd reduction leached N
Farmstar ® France	A\$50 to A\$100/ha
Canopy Management–HGCA report 2002	A\$50 to A\$90/ha
Yarra N Sensor – Germany	A\$90/ha
Yarra N Sensor – potential Australian	A\$28/ha (need 665ha/year to return 2*)
- in Australia	a 3% increase in yield.
Greenseeker ® RT200 in Oklahoma	A\$25 to A\$50/ha
Greenseeker ® RT100 using N-Rich Strip	A\$20/ha

Canopy management has been investigated heavily already in Australia and I believe that it should have place in the medium to high rainfall wheat growing regions in Australia. It is not just about delaying nitrogen inputs, but is a systems approach, that involves using Fungicides if diseases are present, and Plant Growth Regulators. It also allows for delaying crop inputs later in the season when the season's moisture supply and crop's health is more defined.

As Australian farmers have the ultimate goal of passing on the land to the next generation in a better condition that they inherited it, I believe the adoption of Conservation and Precision Farming techniques will help achieve this.

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