Australian Nuffield Farming Scholars Association

The potential for increased nitrogen use efficiency with improved agronomy and developing technology.

Report by Richard Heath

"Pinecliff"
CURLEWIS NSW 2381
Email: richtam2@bigpond.com
Ph: 02 6744 7872
Fax: 02 6744 7849

2002 Nuffield Scholar sponsored by GRDC

GRDC
Grains Research & Development Corporation

Table of Contents

Executive Summary

Each year approximately fifty million tons of fertiliser nitrogen is applied to cereal crops around the world. Only 33% of this nitrogen is recovered in the harvested grain. Applied nitrogen fertiliser that is not recovered in the grain can be lost through leaching in to the water table, surface run off, and denitrification. All of these loss pathways result in serious environmental problems as well as reduced farm profitability. There are a number of different agronomy theories and technologies being developed to improve nitrogen use efficiency (recovery of applied fertiliser).

Nitrogen is a relatively inexpensive input in many parts of the world and has been used as "cheap insurance" for obtaining yield. Incorrect timing of large applications of nitrogen may however create yield limiting situations due to a disruption of the soil water – nitrogen balance. Excess nitrogen can cause rapid and profuse vegetative growth which outgrows the soil water supply and limits grain filling ability. New agronomy strategies are focusing on providing nitrogen to the crop at appropriate growth stages to ensure that the most desirable pattern of vegetative growth is achieved. I investigated approaches to nitrogen management that focus on canopy management through split applications of nitrogen in the United States, Canada, the U.K and Australia.

The most common method of nitrogen application is a flat rate applied across an entire field based on average yields. Variability in yield from year to year and within fields leads to inefficiencies in nitrogen use when a flat rate approach is used. Varying nitrogen application rates to account for in field differences is difficult however as definable yield zones within fields may not necessarily have the same relationship to each other on a year to year basis. A range of crop sensing products is now being developed to try and provide in season determination of nitrogen requirement. The products that I looked at were the Hydro N Sensor and Syngenta Farmstar which both provided recommendations for varying an average rate of top dressed fertiliser within a field. I also looked at the N-Tech Greenseeker, which provided an absolute determination on rate based on crop condition and expected response to fertiliser. The N Sensor and the Greenseeker were both real time applicators, which used optical sensing of crop nitrogen status. Farmstar however is an aerially based remote sensing product that requires analysis of captured images before application.

Precision farming guidelines for nutrient application have been developed in the U.K which use remote sensing to monitor crop growth and make nitrogen recommendations. The recommendations in these guidelines have followed extensive research into crop physiology enabling an understanding of how manipulation of crop structure through nitrogen applications can produce the most efficient yield producing canopy. Many farmers in Australia, predominately in the winter dominant rainfall areas are now approaching nitrogen application from a canopy management perspective. I believe there is potential for improvement in nitrogen use efficiency in areas where split applications of nitrogen have not been common practice such as the northern cropping zones. There is a need for a better understanding of how the most efficient crop growth in terms of water use can be achieved through nitrogen management before precision application techniques for nitrogen will be fully adopted.

Acknowledgements

First and foremost I would like to thank the Australian Nuffield Farming Scholars Association for giving me the opportunity to undertake this scholarship. The five months I spent travelling were full of learning experiences and social occasions that will be hard to surpass. Meeting other Nuffield scholars from around the world also made me appreciate that the Nuffield organisation can continue to provide fellowship and opportunities to expand understanding of agricultural issues. I look forward to a continuing association with Nuffield.

I would also like to thank my major sponsor the Grains Research and Development Corporation for their continued support of the Australian Nuffield Farming Scholars Association.

Larry Murphy, CEO of the Fluid Fertiliser Association was an invaluable help in organising contacts and visits throughout the United States and Canada.

The Opti-Crop organisation also gave me lots of opportunity to spend time with agronomists and researchers in the United Sates. Geoff Lyon in particular was a great help.

I would like to sincerely thank all the Nuffield scholars in the U.K who showed such great hospitality and organised so many people for me to see. On occasions their influence was the key to getting meetings with some of the more "busy" researchers.

Finally and most importantly I would like to thank all my family, especially my wife Tammy and children Ally and Rhiannon for encouraging and supporting me in undertaking this scholarship. My parents and brothers also made it possible for me to leave the farm for such a long time.

Aims and Objectives

In 2001 an agronomy program that our farm is involved in (Opti-Crop operated by Pursehouse Rural Agribusiness Services) conducted some split nitrogen trials on wheat. The results showed that similar, if not greater yields could be obtained from smaller amounts of post applied nitrogen compared to the standard levels of pre applied fertiliser. The agronomy theories used in those trials were a challenge to conventional wisdom on the Liverpool Plains and inspired me to find out just how much more efficient we could become with nitrogen fertiliser.

My main objectives were to look at different approaches to nitrogen management in a range of cropping environments while remaining focused on cereals. I also wanted to look at whether new technology is having an influence on the ability to improve nitrogen use efficiency.

Our Nuffield group left Australia in late February 2003 and spent the first six weeks looking at agricultural and trade policy and "big picture" agricultural issues. The tour encompassed New Zealand, Singapore, England, Belgium, France, Canada and the United States. These six weeks were an invaluable insight into agriculture in general and gave me the opportunity to put a lot of the environmental problems associated with my study topic in context.

I continued travelling after the group tour finished and spent the next five weeks travelling through the mid west of the United States and the Canadian Prairies. My wife and children joined me for a further three weeks in the U.S after which time I finished my scholarship with five weeks spent in England, Scotland and Wales.

1. Nitrogen use efficiency; An Overview.

1.1 The need for better Nitrogen use efficiency.

Why is it necessary to improve nitrogen use efficiency? The first and most obvious answer is that it improves farm profitability. Nitrogen use efficiency is defined as the rate of recovery of applied nitrogen fertiliser. Greater recovery corresponds to greater return on capital spent. In 1999 the world cereal grain nitrogen use efficiency was estimated at 33%. The unaccounted 67% of applied nitrogen equates to US$15.9 billion.

Apart from the on farm economic loss associated with inefficient fertiliser use there is arguably an even greater cost in terms of environmental impact. The nitrogen that is not recovered in the grain or forage is lost through a number of pathways including gaseous plant emissions, soil denitrification, surface runoff, volatilisation and leaching. Each of these loss pathways has local and global environmental consequences.

Soil denitrification is the conversion of plant available nitrate to nitrogen gasses and occurs under anaerobic soil conditions as a result of water logging. The main gas produced is nitrous oxide which is a major greenhouse polluter. Although not produced as plentifully as carbon dioxide, NO_2 has more of an effect than CO_2 in trapping radiant heat and is the fourth largest contributor to the greenhouse effect. The other consequence of releasing NO_2 into the atmosphere is that after exposure to UV light it gets broken into Nitric Oxide which depletes atmospheric ozone.

Leaching of nitrates into rivers and ground water systems is causing serious pollution issues in many areas around the world. Drinking water quality is being reduced and at high levels can be a threat to human health. Nitrate ions (NO_3^-) are converted to nitrite ions (NO_2^-) in the human gastrointestinal tract. Nitrite ions can then react with haemoglobin with the result that the haemoglobin can no longer carry oxygen.

Nitrates that are carried to estuaries and bays by river systems can also cause rapid growth of aquatic plants (eutrophication). Microbial activity which occurs as the plants decay results in depletion of dissolved oxygen causing an hypoxic zone in which aquatic life is unsustainable. Such a zone exists in the Gulf of Mexico and thought to originate from leached nitrates in the Mississippi watershed. The zone shrinks during droughts and increases during floods which indicate that something carried by the river system is causing the problem.

Nitrate Vulnerable Zones (NVZ's) have been developed in Europe as a response to these environmental issues in areas of high ground water nitrate concentrations. In the U.K almost all arable cropping areas have now been placed in NVZ's. Farmers in NVZ's are required to keep detailed records on fertiliser application to show that they do not apply manufactured fertilisers in excess of the crop needs. Restrictions have also been placed on manures with no applications to be made from August to November and the yearly total on arable land not to exceed 170kg/Ha.

I spoke with the Environment Agency who confirmed farmers' reports that the NVZ's had not been successful in reducing nitrate levels to this point. Most farmers however agreed that NVZ requirements had been to their benefit by focusing attention on how efficient they were being with their own fertiliser applications. For example fertiliser spreader calibration services provided by the government had revealed to a lot of farmers how much they were losing through incorrect application.

Application improvements required by the common agricultural policy as well as better agronomy management generally are reflected in the European fertiliser manufacturers association forecasts for fertiliser consumption in the EU. Nitrogen consumption is expected to decrease by 7% over the next ten years even though the production of cereals is expected to increase by 7%.

1.2 How can we improve nitrogen use efficiency?

There are a number of ways of improving nitrogen use efficiency. Organic farming systems that do not introduce mineral nitrogen into the system are extremely efficient at removing what organic nitrogen is present. Yield decreases associated with organic farming practices prohibit this strategy from being used as a realistic production system to supply world needs. Some of the rotational tools used by organic farmers such as incorporating grain legumes and pasture leys are still relevant however and are being increasingly looked at to address a range of environmental problems in annual cropping systems.

Harvesting crops for forage rather than grain also removes more nitrogen thus improving nitrogen use efficiency. Problems associated with this approach include increased dependency on animal based protein and a decrease in retention of soil organic carbon leading to poor soil structure.

Improved nitrogen use efficiency by better varieties can be achieved by selecting for cultivars with high harvest index. Harvest index is the ratio of grain to biomass. The less biomass needed to produce the same amount of grain equates to less nitrogen needed. A large seed breeding company in the U.K, CPB Twyford is reflecting this in the selection criteria they use on plant physiology. They consider smaller more erect flag leaves desirable. This type of plant provides more sunlight to the lower leaves and also helps in reducing leaf disease through better air movement through the canopy.

Genetic manipulation of the nitrogen metabolism of plants can also be used to improve nitrogen use efficiency with a current project in Europe taking that approach. Wheat has been developed with improved nitrogen use by over expression of the enzyme glutamine synthetase. There are many other projects looking at different biochemical pathways and the possibilities of improving nutrient utilisation through their manipulation. For my study however I focused on application techniques and agronomy for existing crop varieties.

The basis for improving the efficiency of nitrogen fertilisers is farming in a manner that the growing plant is provided with no more and no less than it needs throughout the growing season. If nitrogen availability to the growing plant can be timed to provide required nitrogen as the plant is growing then losses will be reduced. Timed released fertilisers are available for the horticulture and garden markets but at this stage are cost ineffective for broad scale agriculture.

The other method for timing the availability of nitrogen to a growing plant is to apply the fertiliser on more than one occasion during the growing season rather than applying the entire crop need at time of planting. Split nitrogen applications were the focus of my study and I spent time looking at the different agronomic approaches to applying nitrogen as well as the technology for determining how much nitrogen to apply.

2. Nitrogen Agronomy

2.1 Iowa

Jerry Hatfield, director of the National Soil Tilth Lab, a USDA research organisation based at Iowa State University in Ames, Iowa has been investigating soil nitrogen – water relationships. The corn growing areas of central Iowa are one of the heaviest yielding areas in the United States. However Dr. Hatfield still believes that yields are sometimes being reduced because of inappropriate fertiliser use.

Plant growth studies showed that potential yield was not being met in low organic matter soils within fields due to soil water deficiencies during the grain filling period. Precipitation data and daily water use studies showed that this was caused by excessive early season water use. Water use efficiency was found to decrease across the field as higher rates of nitrogen were applied. Nitrogen use efficiency and water use efficiency were both lower in the low organic matter soils compared to higher organic matter soils within the same field. During the vegetative stage of growth there is very little difference between plants in either of the soils.

When nitrogen applications were split to supply less nitrogen to the lower organic matter soils early in the season, both water use efficiency and nitrogen use efficiency were increased allowing greater yields to be achieved with less nitrogen applied.

These results are significant because, if corn in high rainfall (900mm/year), high yielding (regularly over 12ton/Ha) areas is outgrowing soil water supply because of excessive early season growth then the implications are that the same patterns would be magnified in lower rainfall, lower yielding areas.

2.2 England

Split applications of Nitrogen have been used for some time in the U.K with their long mild season seen as an ideal environment for spoon feeding of nutrients. Reliable in season rainfall gives a low risk environment for incorporation of top dressed fertiliser. As a result yields of winter wheat are commonly around the 9t/Ha mark and often achieve more than 10t/Ha.

Some agronomy groups and seed breeders however are now questioning whether even those yields are the maximum capable given the climatic conditions and have formulated more strategic plans for split applications of nitrogen. Their philosophies basically echo the sort of results that Jerry Hatfield has been finding in that they are trying to grow the most efficient canopy for grain production which means controlling the amount of early season vegetation.

I met with Simon Francis of CPB Twyford (a large seed breeding company near Cambridge) and he detailed their nitrogen management approach for me. One of the key differences that CPB have with predominant farmer management is a much more critical appraisal of crop condition before applications of Nitrogen in early March. Spring nitrogen applications in the U.K usually occur when the cumulative day degrees hit a certain level indicating the end of winter dormancy and triggering spring growth. A standard application of nitrogen tends to be applied at that stage. CPB's approach is to carefully asses tiller numbers before making this application. Six Hundred heads per square metre are considered to be all that are needed to achieve maximum yield potential. Growing more tillers than this uses more water and nutrients than are needed to achieve maximum yield and also adds to lodging risk and disease potential.

In usual cropping rotations there is often enough soil nitrogen present to achieve the correct level of tillering if the seeding rate has been accurate. The first application of nitrogen should then be made at GS 31/32 (prior to stem elongation) in order to achieve the desired canopy. A green area index of six at GS 37/39 (flag leaf) has been identified as the ideal amount of biomass for feeding any yield. Thirty kilos of nitrogen is needed to grow each unit of GAI, therefore 180kg of nitrogen is needed by the plant to achieve a GAI of 6. To produce the correct canopy therefore 180kg of nitrogen needs to be applied at stem elongation minus any available soil nitrogen and any nitrogen that has already been applied to the crop.

The balance of the nitrogen, determined by target yield, is applied at flag leaf stage to an efficient canopy. The nitrogen prolongs green leaf retention and maximises photosynthetic rate rather than going towards wasteful production of foliage.

This approach is not without its critics. There is a major attitudinal change required before the farmers will be convinced that a thinner yellower crop has higher yield potential than a lush dark green crop.

Two other visits in the U.K endorsed this approach however while recognising that it was a hard sell to a lot of farmers. Stuart Goodinson at Technicrop, an agronomy consulting service near Hereford and Jonathon Blake, a research scientist at ADAS (appendix 2) both recognised that management of crop canopy to avoid excessive vegetation resulted in the most efficient use of nitrogen. Work being done at the ADAS facility at Rosemaund is currently looking at the physiology of Barley to determine appropriate canopy structure for maximum yield in that crop.

2.3 Kentucky

A large proportion of the intensive wheat management strategies used in the Opti-Crop program originated from the United Kingdom where split applications of Nitrogen have been practiced for many years

Split applications of Nitrogen have led to large increases in average yield of wheat in Kentucky. The Opti-Crop agronomy program of intensive wheat management introduced in Kentucky by Miles Enterprises fifteen years ago heavily promoted split applications of Nitrogen combined with other management practices. Wheat yields in Kentucky at that point were remaining static at around 2 tons/Ha. With similar climatic conditions to the U.K, farmers in Kentucky started to question why they could not achieve the same sort of yields. Miles Farm Supplies of Owensboro Ky, decided to start the Opti-Crop agronomy service using a lot of the management principles from U.K farming. The average Kentucky wheat yield is now around 4.5 tons/Ha and most growers there put the increase down to improved management in general with a major part of that being better nitrogen management. Growers realised that applying all the nitrogen for the crop in one early application was promoting excessive tillering and causing lodging and leaf disease.

Timing of applications and levels applied are now carefully monitored to manage the growth of the crop. Soil nitrate levels are tested before autumn applications to ensure that over applications of fertiliser nitrogen are not made causing excessive tillering prior to winter dormancy. Tiller numbers are then counted in the spring and nitrogen applications made accordingly to achieve a target of around 600 tillers m^2. If seasonal conditions are going well the main yield determining application of nitrogen is then made prior to terminal spikelet (GS31). This approach differs from the CPB method in that Opti-Crop believes that for highest yield the number of spikelets on each head must be maximised. The determination of number of spikelets occurs at GS31 so the plant must have access to all its nitrogen prior to this point.

Environmental conditions at grain fill in the U.S are often a lot harsher than the U.K and as a result the season can be significantly shorter. This difference may account for the different approaches to the optimum time for yield determining nitrogen to be applied. The main principle in the two approaches is similar however in that both are aiming at maximising fertiliser efficiencies by growing the most efficient canopy for converting nutrients and water into yield rather than wasted vegetation.

2.4 Oklahoma

Oklahoma State University has a department that has been extensively researching methods for improving nitrogen use efficiency. I met with Bill Raun and Gordon Johnson at OSU who had both been working on nitrogen nutrition for a number of years. Dr Raun and Dr Johnson had studied data from long term fertiliser trials in wheat and corn. Their aim was to determine temporal differences in nitrogen use efficiency and the causes of any differences.

As yields increased with higher amounts of fertiliser, nitrogen use efficiency decreased dramatically. This indicated that excess mineral nitrogen was present in the system above what the plant was able to use. Crop requirement for supplied nitrogen varied greatly from year to year as both the potential yield and amount of yield supported by mineralised nitrogen varied. The crop requirement for nitrogen was calculated by the difference between the highest yielding fertilised treatment and the unfertilised control.

There was found to be no relationship between the yield of unfertilised control plots and the maximum yield of fertilised plots. This would indicate that the environmental conditions that were promoting mineralisation of organic nitrogen to support yield in the unfertilised plots were not corresponding to an increased yield potential in the fertilised plots. This fact led Dr Raun and Dr Johnson to develop a response index (RI) to fertiliser to determine what extent fertiliser nitrogen was needed each year to achieve maximum yield. Crop RI was calculated by dividing maximum yield with nitrogen by yield without nitrogen. When the RI is high it means there has been a large response to fertiliser and conversely when the index approaches 1 it means that there has been virtually no benefit from supplied nitrogen. Raun and Johnson concluded that if a reliable method could be found to determine RI in season, nitrogen use efficiency could be improved dramatically.

2.5 South West Saskatchewan

The U.K and Kentucky are both relatively mild environments for growing cereals compared to a lot of other grain growing areas. I encountered a lot of different opinions on the suitability of delayed nitrogen in lower rainfall, lower yielding growing areas.

Dr Jay Goos of North Dakota State University is convinced that the growing season for spring wheat in North Dakota is simply too short to justify split applying nitrogen. Critical growth stages occur too soon after planting to risk not getting top dressed fertiliser incorporated in time. A lot of nitrogen is incorporated in the Autumn however and this can sometimes lead to large losses as the top 30cm of soil in the spring time can thaw and become saturated. The frozen soil below the top layer prevents the saturated soil drying out and large denitrification losses can occur.

Opti-Crop has recently expanded into North Dakota and the 2003 season saw a large area of wheat managed with split nitrogen applications. The results were not available at time of writing but farmers I spoke to in North Dakota seemed very interested in the concept and willing to give it a try.

Some areas of North America with similar climates to North Dakota have already been seeing some success with split applied Nitrogen. I met with Dean James at the Semiarid

Prairie Research Centre in Swift Current, SW Saskatchewan. Dean works in a team with Fernando Selles and has been researching the feasibility of using split applications of nitrogen to improve yield and grain protein in the semiarid brown soil zone of South West Saskatchewan. Their research has been made necessary by the introduction of protein premiums in Canada and the uncertainty of how to achieve consistently high protein levels in a highly variable rainfall climate.

Applying higher amounts of fertiliser at planting was producing a typical fertiliser efficiency curve i.e. the higher the rate of fertiliser applied, the less efficient the plant is at converting the fertiliser into yield and protein. A study was initiated in 1996 to determine if split applications of nitrogen would be feasible under semi arid conditions. The trial was run for three years and showed highly variable results from year to year. Overall it was found that a split application of nitrogen would increase yield by more than 200kg/Ha, 42% of the time and protein by more than 0.5%, 44% of the time. These increases were more reliable when smaller amounts of seeding nitrogen were applied and the top dress was applied before flag leaf emergence.

The conclusion was made that efficiencies in fertiliser application could be gained by applying around 75% of the crops nitrogen needs for an expected maximum yield at planting and then assessing the season before applying the remainder of the nitrogen as a top dress. If seasonal conditions were positive the remaining 25% or more could be applied with no yield penalty and possible yield increase, if seasonal conditions were poor the second application could be dropped producing a saving in fertiliser.

2.6 Manitoba

Similar split nitrogen trials carried out by Ag Canada in Brandon, Manitoba had not been as successful in demonstrating benefits from splits as the Swift Current work. Cynthia Grant (Ag Canada research scientist) hypothesised that this may be due to the much higher organic matter levels in the black soils of Manitoba. Cynthia felt that there would be a much larger amount of mineralisation during the growing season in the black soil type of Manitoba than the brown soils of SW Saskatchewan and that this would negate the effects of split applied nitrogen. While yield benefits could not be demonstrated in Manitoba through split nitrogen applications it was recognised that there was potential for better quality production. Less dense leaf canopies, caused by delaying nitrogen application decreased leaf diseases. Another as yet unexplained result produced in the Manitoba trials was that increased plant nitrate levels late in the season reduced the incidence of Fusarium head blight. This effect of late nitrogen applications was a newly observed and unrepeated result that Ag-Canada were obviously very interested in exploring further.

2.7 Australia

In Australia there have also been attempts to influence canopy growth to maximise yield and fertiliser efficiencies. A group of irrigated wheat growers in the Murray Valley around Finley, NSW were puzzled over the variation in yields they were observing year to year between different fertilisation strategies. Some years top yields were being achieved with all nitrogen being top dressed while other years the best yields occurred in fields that had some nitrogen applied pre plant. John Lacy from the Department of Agriculture in Finley and John Angus from the CSIRO studied the problem and came up with a nitrogen management plan that had an 8t/Ha yield as its objective.

It was recognised that variations in yield were due to differences in water use efficiency caused by different sized crop canopies. Previous nitrogen management strategies were not paying close attention to the amount of vegetation produced and in some year's early application of nitrogen combined with good mineralisation was resulting in highly excessive tillering and poor water use. The nitrogen management plan worked backwards from the amount of heads needed to achieve the target yield and made sure that any fertiliser applied prior to GS37 did not boost tillering above the optimum number of 600 tillers per square metre.

Fertiliser is applied at planting to provide 100kg/Ha of total nitrogen from fertiliser and mineralised sources. If shoot densities or tiller numbers are below target then small amounts of nitrogen are applied to boost tillering prior to GS30 otherwise the main yield supporting application is withheld until GS37. Obtaining a yield benefit from nitrogen applied at this late stage has been questioned. However the group has found that in irrigated situations, where applied nitrogen can be made immediately available to the plant, the approach has given good results.

2.8 Slow Release Nitrogen Fertilisers

Multiple applications of fertiliser to a growing crop is time consuming and costly. An ideal situation is to apply once, preferably in conjunction with another operation such as seeding and have that fertiliser released slowly to the crop as it is required. Most nitrogen fertilisers convert fairly rapidly into plant available nitrate once they are incorporated into the soil. There are treatments available to delay this process.

Technology exists for coating fertiliser granules with polymers that shield the fertiliser from water in the soil for some time and thus delay the nitrification process. Coated fertiliser products are used in high value horticulture industries but are cost ineffective in broad scale agriculture at this stage.

The conversion to nitrate can also be prevented by nitrification or urease inhibitors which attempt to either deactivate nitrifying bacteria or the enzyme urease, produced by the bacteria and needed to convert ammonium to nitrate. Trials conducted by Ag Canada at Brandon, Manitoba attempted to quantify the effect of Agritain, a urease inhibitor on plant available nitrate. Agritain did not have a long lasting effect but it did reduce nitrification to the extent that much larger amounts of nitrogen could be placed with the seed at planting without seedling damage occurring. This benefit had the potential to improve fertiliser use efficiency since not having to place the fertiliser away from the seed would lead to less soil disturbance which should increase water use efficiency and result in higher yields.

2.9 Determining Rates

2.9.1 Yield variability from year to year

Whichever approach is used for applying nitrogen, a determination has to be made at some stage on targeted yield in order to calculate a final amount of fertiliser for the crop. The advent of yield mapping has quantified yield differences within fields. These yield differences can be significant and improvements in nitrogen use efficiency can be made by spatially varying the amount of nitrogen applied to the field in order that the low yielding areas do not receive too much fertiliser and the high yielding areas reach their full potential. The challenge in doing this is predicting those areas before harvest

Alan Moulin at Ag Canada, Brandon and Dan Long of Montana State University have both found that yield zones within wheat fields are identifiable. The yield zone boundaries are fairly consistent from year to year but the relationship that the zones have to each other is not consistent.

Alan Moulin studied the variability of yield within a field for five years. The conclusion made was that while zones of yield were predictable, the nitrogen requirements of each zone were not. The highest yielding zone in one year may be a low yielding zone the following year dependent on environmental conditions. Nitrogen requirement as a result would vary significantly and varying applied nitrogen based on previous crop removal was not a viable strategy.

Dan Long came to similar conclusions through work at the Northern Agricultural Research Centre near Havre, Montana. Dr Long looked at grain protein as an indicator of nitrogen sufficiency. He found that grain protein levels below 13% indicated that nitrogen had been in deficiency for the plant and had limited potential yield. Grain protein maps were generated for fields, and these correlated well with yield zones and were reasonably consistent in areas from year to year. The relationships of the grain protein zones to each other did vary from year to year indicating that an area within a field that was nitrogen sufficient one year was not the following year and vice versa.

2.9.2 Variable application based on seasonal conditions

The different relationships of the yield zones to each other is based almost entirely on seasonal conditions which are difficult to predict at time of sowing. The technology to spatially vary nitrogen at time of planting based on historical records (either yield maps or soil tests) exists now but its success hinges on the accuracy of long term weather forecasts. Chris Dawson, head of the precision farming alliance in the U.K is of the opinion that it would be possible to create computer software that with enough years of data provided would be able to make reasonable predictions on how soil zones are going to relate to each other. Current information that would be needed to make predictions would be soil moisture status and seasonal indicators such as the SOI in Australia.

A much more accurate way of optimizing the efficient uptake of nitrogen fertiliser is to spatially vary its application based on an in season appraisal of crop condition and seasonal conditions. A decision on yield target can be made with much more precision when the crop is established and growing compared to before the crop is planted.

I met with Gavin Wood of Cranfield University at Silsoe in England who had been involved in a project with the Home Grown Cereals Authority to determine a precision farming strategy for cereals. As part of that study they looked at varying nitrogen using different strategies to calculate rates. Nitrogen varied on the basis of historical yield data gave no overall yield or economic advantages. Varying nitrogen application based on the shoot density of the current crop however resulted in an average yield benefit of 0.46t/Ha compared to standard farm practice. A surprise result was that a field with identifiable soil type differences did not respond as well to variable nitrogen as did a field with an even soil type. This again shows that the best measure for determining nitrogen rates is crop condition rather than historical data such as soil tests.

Decisions on post applied nitrogen rates can be made to any size management unit. There does not necessarily need to be any expensive technology used to make the decision that one end of a field does not have the same potential as the other and adjust a post applied fertiliser application accordingly. Farmers performing herbicide applications or simply doing regular crop walks will know the different areas of the field and what they are capable of. A number of new products are coming on line however that are able to quantify observations of within field differences and are enabling the separate management of smaller and smaller units of area.

3. Nitrogen Application Technology

3.1 Syngenta

Syngenta have entered the remote sensing market in Europe and the U.K with a product that allows determination of appropriate top dressing, plant growth regulator applications and desiccation determinations. My first thought when I learnt about the Syngenta Farmstar remote sensing product was that it seemed well away from their core business. When I asked the Project Manager Quentin Lefaucheux about this he explained that Syngenta saw the need to acquire a remote sensing product as a justification tool for crop chemical applications. Environmental legislation in Europe is moving towards having to justify all agricultural inputs in a manner that proves the necessity of the application. Remote sensing of crop condition is a tool that can be used in the justification process and nitrogen decisions can be made with data from the same images that are used to make the agrichemical decisions. Syngenta therefore have developed a Nitrogen application decision tool as a by-product utilising the technology they need to justify applications of agrichemicals, the manufacture of which is their core business.

Farmstar relies on a series of aerially acquired NDVI (appendix 2) images at various stages throughout the growing season. The images are generally taken in mid February, mid March and mid May in order to monitor the developing crop canopy. The first map and application is used to address tiller numbers while they can still be influenced by nitrogen application. Poor areas of the field indicated by low leaf area indexes (LAI) can be assessed to see whether they would benefit from a higher rate of nitrogen to boost tillering and areas of the field with high tiller numbers (larger LAI) can be receive a lower rate of nitrogen in order to avoid lodging risk later in the season. Similarly once the canopy has been set the later images and applications can be used to determine areas of high potential which can receive more fertiliser and low potential areas for less fertiliser.

The NDVI information is used to generate maps that recommend application rates in terms of deviation from an average rate i.e. the map would not give an absolute determination of rate but would create contours that would indicate average rate, +10kg/Ha, -10kg/Ha and so on. For example at growth stage 37 a farmer may be wishing to make a top dress application of 50kg/Ha of nitrogen. The Farmstar map would then indicate which areas of the field would benefit from higher or lower rates from the farmer determined average of 50kg/Ha.

This approach is not designed to provide a "farming from the office" solution. The Farmstar maps are always going to require some on the ground checking to confirm that differences are not due to non nutrient issues such as weed pressure. What this tool does provide is quantification of differences across fields that may already be known to exist by the farmer but not previously measured in way that provided more efficient application of inputs.

There are currently 40,000Ha of crop being managed using the Farmstar system in France and during 2003 there were 25 farms in the U.K participating in a trial to adapt the system to U.K conditions. Quentin reported that the results in France were very encouraging with one of the main benefits being an improvement in the evenness of the crop creating better harvesting efficiencies. Total nitrogen rates were generally not being reduced because the average rate decisions were still being made by the farmers and were not likely to change. Fertiliser efficiencies were being improved however as a slight increase in yields was being observed.

The Farmstar program is going to be offered in Australia for the 2004 winter season through Terrabyte Precision Ag services from Wagga, NSW. John Medway from Terrabyte informed me that they have signed an agreement with the French manufacturers of the satellites used to acquire the images. The Spot satellite system takes a 60km by 60km image that can be targeted anywhere within a 900km swath width and passes over Australia every three days. Terrabyte will be providing imagery for the entire rice crop for the 2003/2004 season.

3.2 Hydro

Hydro Agri, the largest fertiliser manufacturing company in the world has also seen a need to be marketing technology that ensures fertiliser is being applied efficiently and has developed its own crop sensing technology for variable rate application of nitrogen fertilisers. The Hydro N-Sensor is a tractor mounted optical sensor that acquires NDVI (Appendix 2) information which is used to determine rates for fertiliser application using a variable rate spreader or boom spray.

The N-Sensor looks like an oversized spoiler and is mounted on the tractor or boom spray roof. It uses four optical sensors that scan a fifty square metre area in front of the tractor at a frequency of one reading every second. The recommendations are made in the same fashion as the Syngenta product in that the sensor is first used to scan a representative area of the field. An average rate is then programmed into the applicator for that area and once the machine is operating it makes deviations from the average based on the NDVI of each fifty square metres. Different average rates within fields can be programmed into the controller to account for within field factors other than nitrogen nutrition that can affect yield target.

The sensor also takes ambient light readings to ensure that differences in crop reflectance due to passing cloud cover or other shadow are taken into account. Sun angle does still have an influence on the readings however and the sensor works best between 9.30am and 4.30pm under a consistent cloud cover. The N-Sensor can be connected to any fertiliser applicator that has variable rate technology. Gavin Ray, an area manager for Hydro who has been working extensively with the N-Sensor informed me that they have been getting better results in trials with liquids rather than solids. Gavin felt that this mainly due to the increased precision of liquid application. GPS information is not needed for the N-Sensor to operate, however if the system is connected to a GPS receiver maps can be generated for the scanned data as well as applied product.

Fig 1 The Hydro N Sensor mounted on a boom spray at JSR farms Yorkshire, England

The N-Sensor was developed at Hydro's research station in Germany and has been used in that country for a number of years now. Independent German combine consultants in 2000 found a 20% increase in threshing capacity in fields that had nitrogen applied using an N-Sensor and in 2001 there was a 15% increase in threshing capacity with a 250kg/Ha increase in yield. Evenness of ripening and thus increased harvesting capacity is promoted as one of the benefits of using an N-Sensor. A more even crop is a result of supplying lower yielding areas with less nitrogen and higher yielding areas with more nitrogen. An even application causes lower yielding areas to stay green for longer because of excess nitrogen and higher yielding areas to senesce more quickly because they run out of nitrogen.

Two Nuffield Scholars that I visited had used the Hydro N-Sensor with varying success. David Cousins, General Manager with JSR Farms in Yorkshire felt that the area scanned ($50m^2$) was too large to correct obvious problems within a field that may be associated with single spreader widths. The sensor had detected differences over larger areas within fields however and adjusted accordingly. Jim Wilson who farms near Brechin, Scotland also agreed that the sensor recognised within field differences and adjusted accordingly but felt that the calibration for determining rates needed to be fine tuned. Using the N-Sensor did even up ripening but there was not enough of a yield improvement or fertiliser saving to justify its use economically.

3.3 GreenSeeker™

In 1997 researchers at Oklahoma State University entered an agreement with N-Tech Industries; Ukiah, California to develop an optical sensor based variable rate applicator for nitrogen fertilisers.

OSU research had determined that variation in crop yield due to correctable nitrogen fertiliser application occurred at a sub meter level. Soil or plant tissue testing on this scale is uneconomical so the need for a real time plant sensing based system was recognised. Optical sensors had been developed for commercial use by 1994 and the most commercially successful of these was the Patchen WeedSeeker™. These pulsed light optical sensors were identified as suitable for the proposed variable rate applicator so N-Tech Industries who had taken over the Patchen patent formed an agreement with OSU to develop and market the new GreenSeeker^{TM} sensors.

The field scale GreenSeeker^{TM} applicator used 30 GreenSeeker^{TM} sensors on an 18m boom. Each sensor uses high intensity light emitting diodes that are pulsed at a high frequency. Two wavelengths of light are emitted, red (660nm) and near infra red (780nm) and a photodiode then measures how much of this light is reflected by the target. These reflected measurements are then converted to a normalised difference vegetative index (NDVI) which is used by the nitrogen fertilisation optimisation algorithm to determine the rate of nitrogen applied.

The NDVI measurements are used in two ways by the algorithm. The first step involves a prediction of yield (YP0) if no further nitrogen is added to the crop. NDVI taken at GS30/31 and divided by the number of growing days has been found to correlate well with eventual yield if no further fertiliser is added. This potential yield is then multiplied by the expected response to fertiliser RINDVI (measured by NDVI of a nitrogen non limiting strip divided by NDVI of a strip representative of the rest of the field) to give the predicted yield with added N (YPN).

As outlined earlier the OSU team had determined that harvest RI, calculated by dividing the yield of fertilised strips by the yield of non fertilised strips gave a good measurement of the response to nitrogen fertiliser from season to season. It was found that RI could equally be determined during the growing season by taking NDVI measurements at GS30/31 of a strip in a field that is nitrogen non limiting throughout the growing season and dividing by the NDVI of a representative strip from the rest of the field.

The nitrogen then required to achieve predicted yield (YPN = YP0*RINDVI) is calculated taking grain nitrogen percentage, forage uptake and nitrogen use efficiency into account. YPN is limited with a maximum obtainable yield set by the farmer and RINDVI is also capped at 2 as it was thought to be extremely unlikely that in season applications could result in any more than twice the yield of pre fertilised areas.

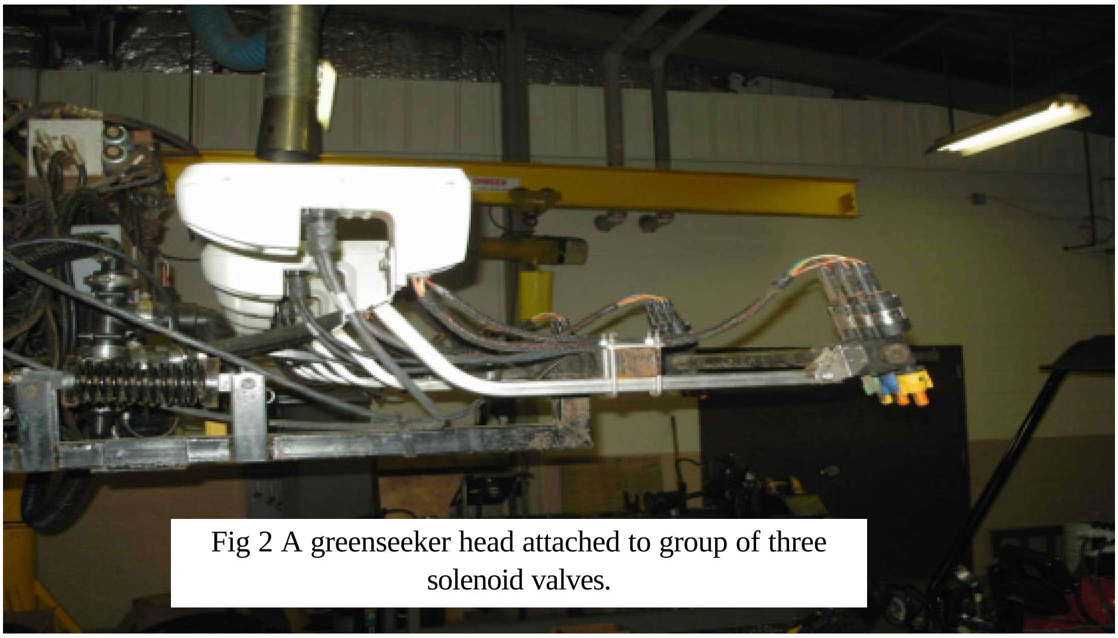

Fig 2 A greenseeker head attached to group of three solenoid valves.

The mechanics of the GreenSeeker™ applicator involve the individual sensors linked with a User Interface (cab based controller). The UI programs each of the sensors with calibration data and the appropriate algorithm so that they operate independently when the machine is running. The sensors each control three solenoid valves that are rated to apply 1X, 2X and 4X rates. By turning on different combination of these nozzles a range of rates can be applied. The UI monitors the application rates of each set of solenoids and ensures that constant operating pressure is maintained. NDVI measurements and application rates are collected by the UI and geo referenced using an attached GPS receiver.

N-Tech also market a hand held GreenSeeker™ unit which consists of a single sensor attached to power source and a palm type computer. The hand held unit is designed to be used while walking through the crop and the software loaded on the palm computer can make nitrogen recommendations that can then be applied to the whole field.

The GreenSeeker™ system has only been commercially available for one year and at the time of my visit there were three full boom units that had been sold in North America. Results from this season (2003) were communicated to me by Robert Mullen, agronomist with N-Tech. Averaged across 8 sites in Oklahoma the GreenSeeker™ treated fields yielded 3.43 t/Ha with 67kgN/Ha split between pre plant and post applied. The nitrogen rich strips at each of those locations yielded 3.6t/Ha with 134kgN/Ha applied all pre plant. While yield increases were not observed this year the savings in fertiliser equated to a $49AUD/Ha increase in margin.

3.4 HGCA (Appendix 2)

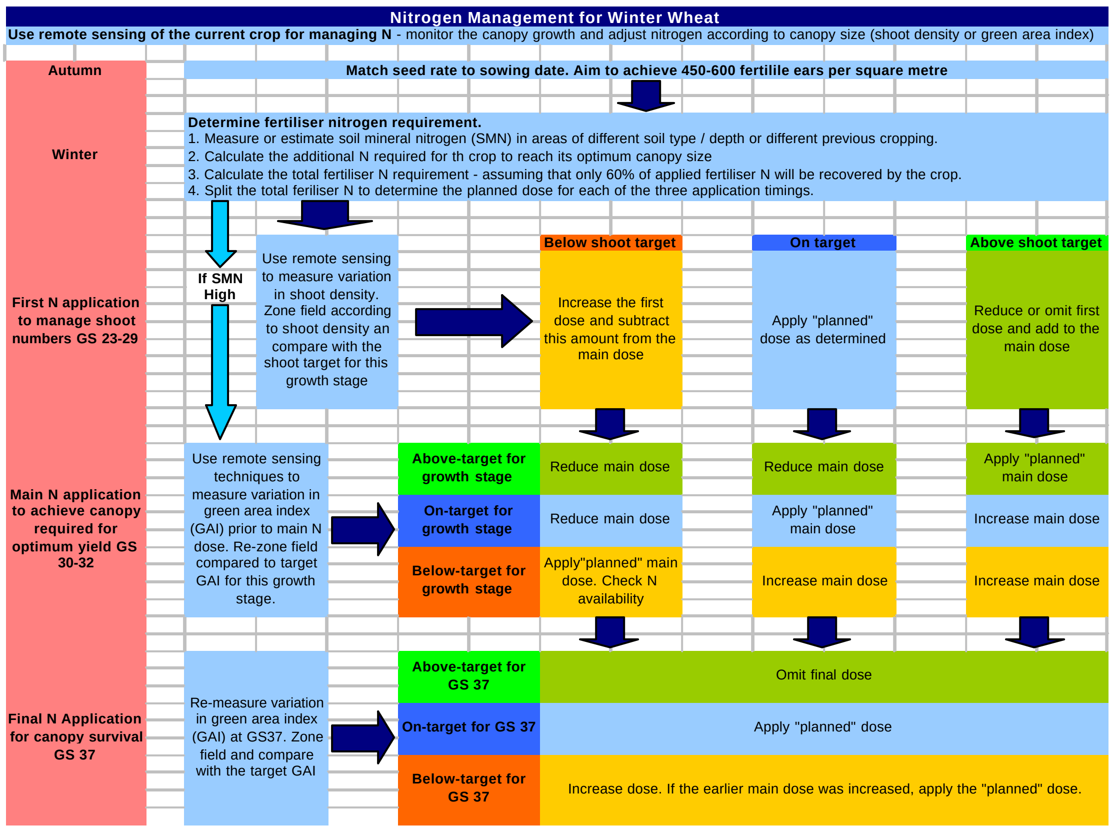

Fig 3 The Nitrogen Management section from the HGCA's guide to "Precision farming" of cereals.

The HGCA "Precision farming of cereals" guidelines were developed after a five year HGCA funded project in co-operation with Cranfield University. Nitrogen management guidelines for winter wheat were formulated that relied on remote sensing to monitor canopy growth and apply nitrogen accordingly.

Three application decisions at GS23-29, GS30-32 and GS37 are outlined in a flow chart that makes rate determinations based on whether the shoot density or green area index (Appendix 2) is at, below or above target for each stage. The target for each stage was determined by another HGCA project that resulted in the "Crop growth guide for cereals". This project determined the most efficient canopy size for each growth stage for maximum grain production.

At each growth stage remote sensed NDVI images (converted to GAI) can either be used to make a flat rate decision for a field or for maximum efficiencies the field can be zoned according to differences in GAI and fertiliser varied accordingly. Wheat fields managed in this manner during the research for these guidelines achieved an averaged benefit of $55AUD /Ha in combined yield increase and fertiliser savings.

3.5 Fertiliser Types

All the technologies and agronomy strategies I've outlined rely on top dressed fertiliser being made reasonably rapidly available to growing plants. Unless the crop is being grown under irrigation a rainfall event after application is required to move the fertiliser into the root zone. Applied fertiliser therefore needs to be stable until rainfall and to be in a form that can be applied evenly and accurately.

Ammonium nitrate is least likely to volatilise after application, however there are problems with availability (for purchase) and accuracy of application. In the United States ammonium nitrate is rapidly becoming unprocurable as the government tries to restrict its availability due to the threat posed by terrorists using it in fertiliser bombs. An agronomist that I spent some time with in North Dakota had tried to purchase a small amount of ammonium nitrate for a fertiliser trial and had been required to submit his details for an FBI check that would have taken several weeks to clear. The ammonium nitrate did not make it into the trial. In other countries (including Australia) ammonium nitrate is still available but is amongst the most expensive forms of nitrogen. Being a dry product it also needs to be applied with a disk spinner or air boom or applied by air. While spreading technology is a lot more accurate now than it has been in the past it is still not as accurate as liquid application and cannot be varied on as small a scale as liquids.

There are a number of liquid nitrogen formulations the most common of which is urea ammonium nitrate or UAN. Half of the nitrogen in UAN is in ammonium form so it is not as susceptible to volatilisation as plain urea but is slightly more susceptible than ammonium nitrate. UAN can be applied accurately and evenly and can be varied on a per nozzle basis. In North America generally there has been quite a big swing towards liquid fertilisers of late with compliance issues around other forms of fertiliser being one of the big factors causing this move. Anhydrous ammonia, the cheapest and most commonly used form of nitrogen in America and Canada can be used in the manufacture of the amphetamine, crank or crystal meth. Costs associated with protecting anhydrous ammonia from theft for drug production as well as compliance costs associated with workplace safety are driving manufacturers and distributors to provide and promote alternative forms of nitrogen with liquid formulations at the forefront.

Many co-ops now supply a range of liquid formulations mixed on site and the cost of UAN in some areas is now equivalent to Urea on a per kg of N basis. Larry Murphy, CEO of the Fluid Fertiliser Foundation of America told me that there is starting to be a reasonable amount of anecdotal evidence that 1 to 1 one ratios of phosphorus and nitrogen in liquid formulations seems to make both nutrients travel more rapidly into the root zone. I spoke to some farmers in Kansas who had good results dribble banding phosphorus/nitrogen mixtures at planting.

Compliance costs are also causing a change in the predominant fertiliser type in the U.K. However it is the opposite move to that seen in the United States. In the U.K there is a current move away from liquids back into solid fertilisers. I spoke to Jane Salter from the fertiliser manufacturers association who was most concerned about the reasons behind the move back to solids. In recent years there have been a number of liquid fertiliser spills in the U.K that have resulted in severe and highly publicised environmental pollution. Responding to these spills the government has put in place costly storage and handling requirements for liquid fertilisers and is threatening even tighter legislation if any more incidents are recorded. The concern from the FMA is that while the liquid spills have been highly visible they also have very localised effects that do not have a huge impact on the environment as a whole. Compliance costs placed on liquids are forcing a move back to solids which can not be applied as accurately as liquids and are arguably less efficient overall resulting in a larger but less visible overall impact on the environment.

4. Marketing opportunities from better nitrogen management

Nitrogen management that accounts for seasonal differences should, if practiced correctly produce more even quality grain from year to year. A more consistent production of quality grain presents opportunities for closer relationships between producers and end users.

Siemer flour mills in Kentucky have recognised this and entered into an arrangement with Opti-Crop growers to purchase grain grown under Opti-Crop management principles at a premium to the market. Siemer believe that the even quality of Opti-Crop wheat allows them to run their mill in a more efficient manner and the cost savings produced allow them to pass on a premium to the grower. Siemer also benefits by being able to form relationships with premium biscuit manufacturers who recognise the better quality of Siemer's flour. A quality link exists all the way from the consumer to the producer.

Increased milling efficiency gained in the Siemer flour mill is a result of the identification and consistent production of a set of end user traits. Specifications of end user traits are increasingly being defined and refined by processors both as a means to increase processing efficiencies and to be able to differentiate products. While the influence of nitrogen on total protein content of grain has been known for some time, the effect of different fertiliser regimes on protein qualities such as the amount of high molecular weight glutens is less well defined.

I visited Western Plant Breeders in Bozeman, Montana. They do a lot of work on identifying protein quality characteristics of different durum varieties in the breeding process. Dan Biggerstaff who oversees their research and development believes that protein quality characteristics were mainly determined by the genetic capability of the plant. The nutritional requirements for the plant to reach its genetic potential are not necessarily widely known by the growers however. End users such as Durum manufacturers are aware of the nutritional requirements and source wheat from different growing locations with different fertiliser practices and blend to achieve their specifications. The potential exists for agronomy groups to grow wheat under specific practices aimed at achieving the exact specifications required by the processors.

While Dr Biggerstaff believes that protein quality is genetically determined there has not been a lot of research done to back this up. Hydro market their Nufol foliar nitrogen fertiliser with the claim that grain protein with some of its nitrogen sourced through the leaves is more likely to produce high molecular weight glutens than grain protein that has had all its nitrogen sourced from the soil.

In the past there has not been enough benefit in the differentiation of end user traits to justify research into how they can be influenced agronomically. Processors and marketers are now realising the efficiencies gained by consistent production of tight specification end user traits, and money is just starting to flow into projects determining how much those end user traits can be influenced by farmer practice. I believe that nitrogen management practices that ensure consistent production of quality grain will provide marketing opportunities above the associated yield and fertiliser saving benefits.

Conclusions

I believe that nitrogen use efficiency can be improved in cereal cropping in northern grain growing regions of Australia. Given that Australian environmental conditions determine that there is a large variation in yield potential from year to year, there follows a similarly large variation in nitrogen requirement. While winter dominant rainfall areas of southern Australia have been addressing this seasonal difference through top dressing strategies, northern grain growing regions mostly rely on supplying all the crop nitrogen requirements at planting. It is in fact now being shown that in many circumstances providing all the crop's nitrogen requirements at time of planting may be yield limiting due to a disruption of the soil water-nitrogen balance. Developments in the two aspects that I have focused on, agronomy and technology, have provided an opportunity to approach nitrogen management from a different perspective to the predominant concept of "insurance" nitrogen.

In the U.K especially, cereal crops are now being managed with much more attention to production of an efficient yield producing canopy. This has been made possible due to extensive research on canopy development and how that canopy can be manipulated on a spatially variable scale. Research of this type needs to be done in Australia to determine how much canopy manipulation is possible in much harder growing conditions. The potential improvement in nitrogen use efficiency that could be gained from a better understanding of the most efficient yield producing canopy is large.

The technology to monitor and determine differences in crop condition, vital for the most efficient in season applications of nitrogen, already exists and in some cases was developed in Australia. Application of this technology is still in its infancy however, mainly due to a lack of information on what to do with the data once it is acquired. I believe that uptake of this technology will remain low until there is a better understanding of the type of crop growth that is desirable and manageable using crop sensing technology. Development of procedures for in season calibration for nitrogen requirement will also enhance the uptake of crop sensing technology.

Appendix

Appendix 1. Crop Growth Stages.

Zadoks Growth Stage	**Description**
10	First true leaf emerged
21	First tiller visible
22-29	Tiller formation continues
30	Tillering completed, leaf sheath begins to lengthen
31	First node detectable – Spikelet formation complete
32	Second node detectable
37	Last leaf visible (flag leaf)
39	Flag leaf collar visible (early boot)
45	Head in flag leaf sheath but not visible (boot stage)
49-50	First awns or spikelet just visible
53	25% of head emerged
55	50% of head emerged
57	75% of head emerged
59	Head fully emerged
60	Beginning of flowering
69	Flowering completed
71	Kernel watery ripe
75	Milk stage – lower leaves losing colour
85	Soft dough stage – flag leaf losing colour
87	Hard dough stage - head losing colour
91	Kernel hard stage – rapid drying

Appendix 2. Glossary.

NDVI: (Normalised Difference Vegetative Index) is an index that is calculated from the red and near infra red spectral wavelengths reflected from a crop canopy. NDVI values indicate how much green vegetation there is in a certain area.

GAI or LAI: (Green or Leaf Area Index) can be calculated from NDVI values or measured manually and is the ratio of leaf area to ground area.

HGCA: Home Grown Cereals Authority

ADAS: Agricultural Development and Advisory Service.