“Arable input efficiency”

Nick Ward 2009

Nuffield Farming Scholarships Trust

THE LINCOLNSHIRE AGRICULTURAL SOCIETY

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CONTENTS

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INTRODUCTION

I grew up on a farm in Lincolnshire and after time away at the University of Newcastle, travelling Australia and New Zealand and a spell training and working as an agronomist, I have now returned to the family business.

We are an intensive operation producing 2500 acres of wheat, oilseed rape, field beans and peas. Many of the crops are grown for seed production with the emphasis on yield and maximising marginal revenue. Soil types on the farm are medium to heavy. Cultivation policy is based around deep non inversion tillage and a small proportion of the farm is ploughed annually.

BACKGROUND

Agriculture has entered into a period of tremendous volatility both in terms of the value of commodities produced and also the cost of the necessary inputs required to produce a crop. As a producer the recent significant cost fluctuations in seed, fertiliser, agrochemicals and fuel have had a huge impact on our business.

The risk associated with growing a crop has increased significantly. A crop of wheat for harvest in 2007 cost approximately £240 per hectare in inputs. By harvest 2009 this will have risen 250%. Over this period fertiliser prices have quadrupled, fuel and seed costs doubled, along with significant rises in the cost of many agrochemicals.

Global demand has been responsible for these price hikes as marginal land comes into production due to rising output values. A secondary effect is that supply has become an issue with limited availability of some products.

It is likely that supply issues will continue as agriculture brings millions of extra hectares into production over the coming years. The global demand for food is set to double in the next thirty years.

Whilst input prices have eased in 2009, it is likely that this is a short term phenomenon and for this reason we must look for efficiencies in the way that these materials are used on farm. The bottom line is always a key driver but looking ahead availability may become a bigger one.

As a society we have also bought into the concept of reducing greenhouse gas (GHG) emissions in an attempt to mitigate against climate change. The UK government has a target of an 80% reduction in GHGs by 2050, and a 42% reduction by 2020 (both relative to 1990). As yet agriculture has been largely unaffected by this development. Additionally, as multiple retailers strive for themselves and their products to become carbon neutral it is only a matter of time before we all become accountable for our own contributions. For this reason I have not only looked at what we can do regarding cost management but also for any potential efficiencies that may be achieved relating to our use of inputs and GHG emissions.

OBJECTIVES AND METHODOLOGY

My travels took me to the USA, Canada and Australia to look at a range of different practices. I have tried to identify techniques that can reduce the amount of seed, fertiliser, chemical and fuel we use whilst bearing in mind the associated environmental considerations.

It is important to point out that I am trying to increase the ratio of crop output to applied inputs. This measure of efficiency is very different to simply cutting costs. By improving the conversion of materials applied to yield, the maximum margin is realised as opposed to simply minimising the cost.

I have spoken to farmers, consultants, scientists, machinery manufacturers, distributors and agronomists to see how we can improve on our current approach.

1. EXECUTIVE SUMMARY

1.1 Controlled Traffic Farming (CTF)

A well established crop is without doubt the most effective way of converting inputs to crop output. Soil health and management are a key part of achieving this and maintaining optimum conditions throughout the life of the crop. In a conventional, randomly trafficked system, it is estimated that 127% of the area is driven on. This leads to widespread soil compaction.

It is estimated that over 30% of all Australian crops are now produced using Controlled Traffic Farming. This system removes virtually all mechanically induced soil compaction by confining all operations, including planting and harvesting, to set tramlines. The consequential benefits to the soil structure and soil biodiversity are incredible.

The lack of compaction in these soils allows plants to produce deeper roots and access more of the available nutrients and water. The associated reduction in compaction necessitates either less or no cultivations which in turn allows soil organic matter levels to build. As explained to me by several leading soil scientists in Canada and the USA, cultivations lead to reductions in soil organic matter by oxidation and losses to the atmosphere as carbon dioxide.

As organic matter levels increase, so does the nutrient holding capability of the soil and the amount of biological activity within it. The soils then become better at cycling nutrients and effectively feeding the crop.

1.2 Strip Tillage

Practised in large areas of the central USA, strip tillage is a form of site specific cultivation. Only a strip into which a crop is to be planted is cultivated. The area between the rows is left untouched.

Zero tillage is widely accepted as the ultimate environmental establishment system because of reduced soil erosion and run-off along with retention of organic matter. Strip tillage infers all these benefits to the areas between the rows, but still providing a cultivated zone and improved drainage along the row.

Strip tillage is used in poor draining soils where zero tillage is not appropriate and in wide row crops. In addition to reductions in the area being cultivated and the associated savings, its real benefits come from the associated precision banding of fertiliser within the row. Modern centimetre accurate GPS guidance or RTK (Real Time Kinematic) systems allow the cultivation and fertiliser to be placed in the autumn and the crop to be planted directly above it in the spring. 25-30% reductions in fertiliser are achieved with this technique.

1.3 Farming accurately

The Australians have grasped Precision Farming (PF) due to the large areas and variability of soils with which they operate. However the data producing side of PF can be full of pitfalls.

Yield maps are a classic example. We generate them, but then what? Often nothing. At the University of Sydney I was shown how they use yield maps to validate yield expectations based on topography and soil surveys done using soil electrical conductivity. Yield potential can be estimated based on soil depth and texture. Fertiliser applications are then made based on potential productivity. The yield maps also produce data for the replacement of nutrients removed. All this is done without high intensity soil grid sampling.

Similarly the Canadians are using a database of satellite crop imagery to produce management zones for fertiliser applications without even stepping in the field. Farmer's Edge Consulting will this year produce fertiliser recommendations in this way on one million acres. The same company is preparing to use the technology to establish a protocol for reducing carbon emissions through reduced fertiliser use associated with variable rate applications.

Developments in GPS technology have allowed the Australians to take band spraying to new levels. Oilseed rape crops are routinely sprayed between the rows with non selective herbicides using shielded sprayers. Similarly boom sprayers have had the nozzle spacing configured to match row spacing. Inter-row and above row spraying is possible by inserting blank nozzles wherever no chemical is required. In this way a 50-75% saving in chemicals can be achieved. This is facilitated in controlled traffic systems where everything is planted extremely accurately.

1.4 Bio-agtive exhaust gas fertiliser

Canadian farmer Gary Lewis has developed a system to collect, cool and inject tractor exhaust emissions into the soil during fieldwork. Marketed through his N/C Quest company, the system is supposed to reduce or remove the need for subsequent fertiliser applications to the crop.

Exhaust contains heat, water vapour, trace elements, carbon dioxide and nitrous oxides. These are thought to be highly beneficial to soil microbial activity. Exactly how it works is not yet fully understood and trials are ongoing to find out.

As an environmental technology it is possibly without parallel. The savings in product use, manufacture, haulage and field losses through leaching and emissions are substantial and quantifiable. The cost savings are offset by lower yield, but this delivers more environmental savings in the form of less storage, drying and haulage of produce.

1.5 Biotechnology (GM)

GM is no longer just about herbicide tolerance. Stacking of multiple traits into one variety is now happening. Multiple herbicide tolerant traits to combat weed herbicide resistance are combined with multiple insecticidal traits to combat insect pests and resistance selection.

These increases in the plant's ability to withstand pest attack result in improved rooting and drought tolerance. A nitrogen efficiency gene is also in the pipeline along with other consumer orientated characteristics.

In the USA, a farmer's life is getting easier. Productivity is increasing. Profitability is increasing. Yields are increasing. The efficacy of these traits is better than the sprays they are replacing. The number of times they spray is decreasing. The amounts of pesticide and fertiliser they handle and use is decreasing. They are benefiting and so is the environment.

In the cotton growing region of South Australia before the introduction of GM cotton, producers routinely sprayed crops 18-19 times per season with the most toxic of insecticides known to agriculture. The air would permanently smell of insecticide. With Bollguard GM cotton this has been reduced to just two applications per season.

It is a trade off. Spraying is generally disliked in the UK and we have a rapidly diminishing pesticide armoury through legislation and efficacy. The answer could be in the bag.

1.6 Strip intercropping

Seed, fertiliser and chemical may be considered important inputs. Sunlight however is essential. US farmers are maximising crop output by planting alternate strips of soybeans and maize in the same field to utilise more of the available sunlight. The yield increase in the grain maize more than offsets the yield detriment to the soybeans. The system generates an increase in output of 10-15% using the same amount of inputs.

This system is facilitated by the use of GM crops. The agronomy is then very tightly aligned, meaning that the two crops can receive the same inputs at the same timings.

1.7 Biochar

Biochar has been described as a ‘double dip’ for agriculture. Essentially charcoal, it is produced from any form of organic matter including crop residues and wastes by a process called pyrolysis. It has been found to have tremendous value as a soil amendment by increasing the Cation Exchange Capacity of soils. This consequentially increases the nutrient holding capability of the soil resulting in reduced leaching of nutrients and lower nitrous oxide emissions. The finely ground material also has a structure very similar to naturally occurring soil organic matter and is extremely stable over a very long period once in the soil.

The second benefit is that it retains up to 50% of the carbon present in the parent material. Once safely buried in the ground, this carbon has been drawn from the atmosphere and effectively placed in an irreversible form. Unlike many other carbon capture and storage schemes it is quite unique, as it is possible to accurately quantify how much carbon has been sequestered.

Even though some energy is effectively being buried, energy can still be produced during the production process. Research has shown that even at today’s energy and fertiliser prices the net gain in soil productivity is worth more than the value of the energy that is left in the charcoal.

As the EU and the rest of the world looks for reliable ways to capture and store carbon, the case for biochar is being pushed forward as a suitable proposal. At present the production costs are prohibitive but if and when the cost of carbon increases, agriculture could be very well placed to benefit from this technology. Biochar has the potential to make agriculture carbon negative

1.8 Conclusions and recommendations

Soil health is a huge priority and CTF is definitely a way forward but is very much at the concept stage in the UK. Some pioneering farmers are currently attempting to overcome some of the technical difficulties associated with it. CTF Europe is a farmer group encouraging the discussion and dissemination of ideas. They are an ideal starting point for anyone considering CTF.

According to CTF Europe, studies have shown that the system can reduce fuel usage by 35%, reduce energy costs by up to 70%, give 15% better recovery of nitrogen fertiliser, increase infiltration of water reducing soil erosion by 40 % and improve soil aeration leading to reduced nitrous oxide and carbon dioxide emissions.

Strip tillage is a compromise suitable for wide row crops such as oilseed rape, field beans, sugar beet and maize. It could also provide an alternative to the current DEFRA proposal for over winter cover crops preceding all spring sown crops.

The concept of precision banding of fertiliser is already starting to catch on and is a relatively simple system to adopt on farm. The same technology can also be used for band spraying of chemicals. A significant reduction in the amounts of materials used can be achieved in this way.

Growers already using high accuracy GPS in the form of RTK will find that it is a tremendous 'enabling' technology moving forward. The cost of this can be minimised by potential users co-operating or subscribing to existing networks.

Much of the UK Precision farming industry is in the hands of manufactures of hardware or inputs. I would like to see more farmer groups undertaking knowledge share and doing on farm trials to evaluate systems. Australian farmer group SPAA have a tremendous following of farmers to the extent that the manufacturers are now involved after initially being very reticent.

Equally, leading research groups that have funding appear very reticent to step into the realm of PA. Consequently there is very little impartial work done to evaluate new systems such as crop sensing and variable rate technology.

Universities and colleges in the USA have some fantastic training courses for farmers to attend regarding the gathering, interpretation and analysis of spatial information and general understanding of PA.

Nitrogen fertilisers account for 80% of on farm GHG emissions through use and associated manufacture. Site specific applications in the form of in-row placement and VR applications can not only save cost but have a massive impact on our environmental profiles.

We need more creative agronomy to think our way round many of the challenges with which we are faced. Blanket spraying of every acre is not sustainable. Site specific applications within fields are. The driver for change has to come from the farmer and agronomists should be asked to help deliver it.

GM without doubt offers some very robust solutions to a lot of problems and is the one technology that can deliver both cost and environmental savings in a big way.

Biochar is not commercially viable at present, but given political commitment to cut carbon emissions in the medium term this could be at the forefront of carbon capture and storage schemes. In this case agriculture could be well placed to profit from the use of biochar as a soil amendment and also from acting as a carbon sink.

2. CONTROLLED TRAFFIC FARMING (CTF)

2.1 What is it?

CTF is a system of tramlines within a field that are used when undertaking all fieldwork operations. In the UK tramlines are used for spraying on virtually all farms. CTF takes this one step further by using a set of wheelings for cultivations, planting, applications and harvesting.

These wheel tracks remain in place from year to year and are either between the rows of wide row crops or planted over in the case of cereals.

2.2 Why is it relevant?

Soil has to be in optimum condition to produce maximum yields. If this is not the case it will become a production constraint. Crops will still require the same if not more inputs in an attempt to maintain output and the ratio of inputs to output will increase.

2.3 How is it done?

Bout widths of all equipment have to be matched exactly to the rest of the system. For example a 30' wide seed drill would use the same wheelings as a 30' wide cultivator and combine. A 90' sprayer would then be used to span three of these beds using every third wheeling. The necessary accuracy is achieved using GPS.

Watered down versions of CTF are also used where it is difficult to match bout widths or capital expenditure prohibits a wholesale change of equipment in the early years of adoption. Most notable here are combines as they often have a header width which does not readily fit a system.

Matching the track width (width between wheels) of different machines can also be difficult. For example a combine is much wider than a standard sprayer. In a true CTF system the track widths of all vehicles would be matched up.

2.4 Real Time Kinematic (RTK)

RTK is a GPS system than employs a land based correction signal to give pass to pass accuracy of two centimetres. Unlike other satellite based correction signals, RTK also has the benefit of year on year repeatability and is proving to be an incredible 'enabling' technology for many new techniques. It is opening up options that were previously conceivable but not practical.

CTF only really works if done to centimetre accuracy to avoid overlap occurring between passes with machinery. Tramlines can be mapped, stored and reused without any degradation of accuracy over a subsequent time period. Satellite based correction signals will drift over time and stored co-ordinates will not exactly match field locations.

The most significant factor of it is that anyone can operate it. Auto guidance systems and especially those using RTK can make an exceptional machine operator out of a moderate one.

2.5 Removal of compaction

Possibly the biggest impact of isolating compaction to known wheelings is that cultivations are no longer necessary to repair soil structure from mechanical damage on the rest of the area. I would estimate that at least 50% of the cultivations we do annually on our own farm are for this reason. It is virtually impossible to avoid as machines have to go onto fields to perform essential operations, often when the conditions are sub optimal.

Min till or zero till does not work on many soils for this reason. If the compaction is not removed, the soil will subsequently become waterlogged especially on heavier, poor draining soils. Once the soil is waterlogged it then becomes anaerobic and soil biology perishes.

Controlled traffic will overcome this issue by maintaining the porosity of the soil allowing water to more readily permeate down through the profile as illustrated on page 10. Sandy soils are actually quite difficult to deal with and are prone to slumping and compacting due to sand particles washing down through the open pores in the soil and effectively blocking up these airways. Deeper cultivation is often required in a conventional approach, however increased levels of soil organic matter through reduced tillage practices can help negate this problem.

2.6 Soil Health

As the soil organic matter levels also start to build in the top layer of the soil so does the amount of soil microbial activity. As explained by Canadian soil scientist Dr Kris Nichols, aggregation of particles occurs within the soil over a period of time. This is the build up of microbes, organic matter and other life forms around soil particles, which causes a beneficial change in soil texture. The porosity of the soil increases, more air gets in and everything thrives. Any water logging and associated anaerobic conditions will stop this process and also reduce beneficial populations that have built up. Cultivations can also destroy much of the aggregation that has occurred.

The soil foodweb begins with plant matter and everything feeds off this. According to Dr Nichols 'a handful of soil contains more organisms than the total number of people who have ever inhabited the earth'. However this population requires care through good soil management. The microbial foodweb has the ability to feed plants. The soil contains all the nutrients that a plant requires, but many are in an unavailable form. This is the equivalent of being at sea with no water. The microbial foodweb around the plant roots gain their essential carbon from the plants and in return produce more plant available nutrients as a by product. In this way the soil builds its' ability to feed a crop, but all of this can be undone with overly aggressive cultivations.

2.7 CTF in practice

CTF in Australia has taken off in a big way. An estimated 30% of all crops are now produced using some sort of controlled traffic system. Broadacre crops such as cereals constitute the bulk of this area, but higher value crops such as cotton, sugar cane and vegetables are also being produced by this system.

Robert Ruwoldt of Horsham, Victoria maintains that you do not know the true extent of your compaction issues on farm until they are removed entirely. Only then can you see that areas previously thought to be compaction free were suffering to some extent. He is now fastidious about driving only in tramlines, even in pick-up, whenever in the fields on his farm.

The photos above show a study undertaken by Robert Ruwoldt to illustrate the impact of compaction to soil permeability. The left is a wheeling and the right is an uncompacted area.

Robert is a pioneer of min-till, zero till and CTF. He is recognised in Australia to have made massive improvements to his soils, yields and profitability through adoption of these techniques. After 20 years of reduced tillage the soil biological activity has increased to such a level that crop residues are decomposed extremely quickly, releasing nutrients to the subsequent crop that would usually be locked up and unavailable. This increased nutrient cycling has led to significant reductions being made to applied N, P and K fertiliser rates.

One of the main drivers of Australian CTF systems is to improve the permeability of the soils to water. In a climate of minimal rainfall it is essential to be able to 'bank' any precipitation in the soil whether it is in crop or between. In many cases a grower will only plant a crop when they are sure they have a full profile of soil moisture. Then only enough rainfall is required for establishment and subsequently the soil moisture reserve will be enough to produce a crop in the event of drought conditions. Robert also commented on how the creeks and drains in the area now ran less water in the event of significant rainfall because of the fact that the soils were absorbing it much more effectively now. As a consequence, surface erosion of soils has been greatly reduced.

2.8 Residue management

In Canada and Australia where there is much zero tillage and min-till practised, it is felt that the best way to deal with crop residue is to leave it stood up in the form of a long stubble. The emergence of RTK means that it is now a straight forward procedure to then plant the following crop precisely between the rows of the previous crop.

The root of the previous crop is left undisturbed which gives the added advantage of binding the soil together and virtually eliminating the risk of soil erosion through wind blow. This is a massive issue on many of the more fragile North American and Australian soils.

The photo on the left shows the Daybreak seeder in operation seeding between the rows of a previous year's barley crop.

The crawler operates on 12" belts to fit between the 15" rows.

It can be seen running along the track marks made by the combine at harvest.

Location : Rob Ruwoldt , Horsham

2.9 Challenges for CTF Systems - Planting

To plant between the rows of the previous crop sounds relatively straight forward. However given the need to keep the tractor using the same wheelings from one year to the next, it means that the implement has to be offset.

One way to do this is with offset hitches. The disadvantage is that once shifted to the side, the planter has an overlap on side and a gap on the other. This can be overcome by adding an additional row and accepting an overlap on another coulter respectively.

Two 3 point hitches that have been configured for offsetting to suit different row widths

Daybreak manufacturing of Queensland, Australia have come up with a novel way of overcoming this issue. Instead of shifting the planter over permanently, it moves across hydraulically on a carriage. This means that the offset can be maintained to one side regardless of direction of travel. An additional benefit is that the movement can also be used for implement steering to maintain exact positioning of the machine on side slopes.

Daybreak seeder

Hydraulic side-shift for inter row sowing (top view)

2.10 Challenges for CTF Systems - Harvesting

In Australia the most popular width for the system is 30 feet. 35 and 40 feet are other popular options, however they lead to issues when unloading the combine on the move as the chaser bin usually has to move out of the next set of wheelings to get close enough to the harvester to unload. It is possible to overcome this with auger extensions on either the chaser bin or the harvester.

Jamie Grant of Dalby, Queensland has modified this chaser bin. It has an offset hopper and auger arrangement attached.

This enables the combine auger to reach it whilst still remaining in the adjacent traffic lane.

This is a greater problem in the wider 35' and 40' widths where combine auger extensions are not sufficient.

A second issue arising from the wider widths is that of spreading the crop residues effectively behind the combine. Due to the fact that CTF tramlines are likely to be in place for a long time, poorly spread residues will become a problem if it happens year after year. The repeated poor distribution will become visible in the subsequent crops. Fitting an extra wide set of hydraulically driven straw spreaders after the straw choppers is a way around this.

A combine fitted with a set of hydraulic straw spreaders to get an improved distribution of residues.

These are in addition to the straw choppers.

2.11 Challenges for CTF Systems – Track width

CTF requires all vehicles to have on the same track width. The starting point is usually the harvester and everything is made to match that. Three metres and 120 inches are the most common in Australia.

The cheapest way to widen wheel equipment is using 'cotton reels'. These are a spacer that fits between the wheel and the hub to create the extra offset. These do create extra stress on the axles and consequentially tractor manufacturers are not keen.

'Cotton reel' type axle extension

Cast axle extension by Towoomba Engineering

As yet the major manufacturers do not offer wide track width options other than on some crawlers such as John Deere and Agco. A second option offered by specialist fabrication companies such Towoomba Engineering , Queensland who will modify existing axles. This is done by cutting the axle and welding in an extension.

2.12 Challenges for CTF Systems – Deep wheelings

As can happen with sprayer tramlines that get used when wet, a rut is formed. The same can happen in CTF situations. However due to lack of cultivations it is not as easy to level them out.

David Brownhill with the machine he uses to rectify CTF tramlines which have been deepened through repeated use.

As the wheelings remain in the same place every year, it is important to be able to level them out should the need arise.

2.13 Quantifying the benefits – Yield analysis

Iowa farmer Clay Mitchell has taken CTF to another level by trying to quantify what is happening. As he explains, in a conventional system fieldwork happens in a very random fashion. It may be ploughed one way, then cultivated and planted in two more directions. At harvest the residue may be poorly spread at another angle. This criss-crossing of vehicles produces a lot of ‘background noise’ when it comes to yield. Some areas will have been run on seven or eight times during the season and some not at all.

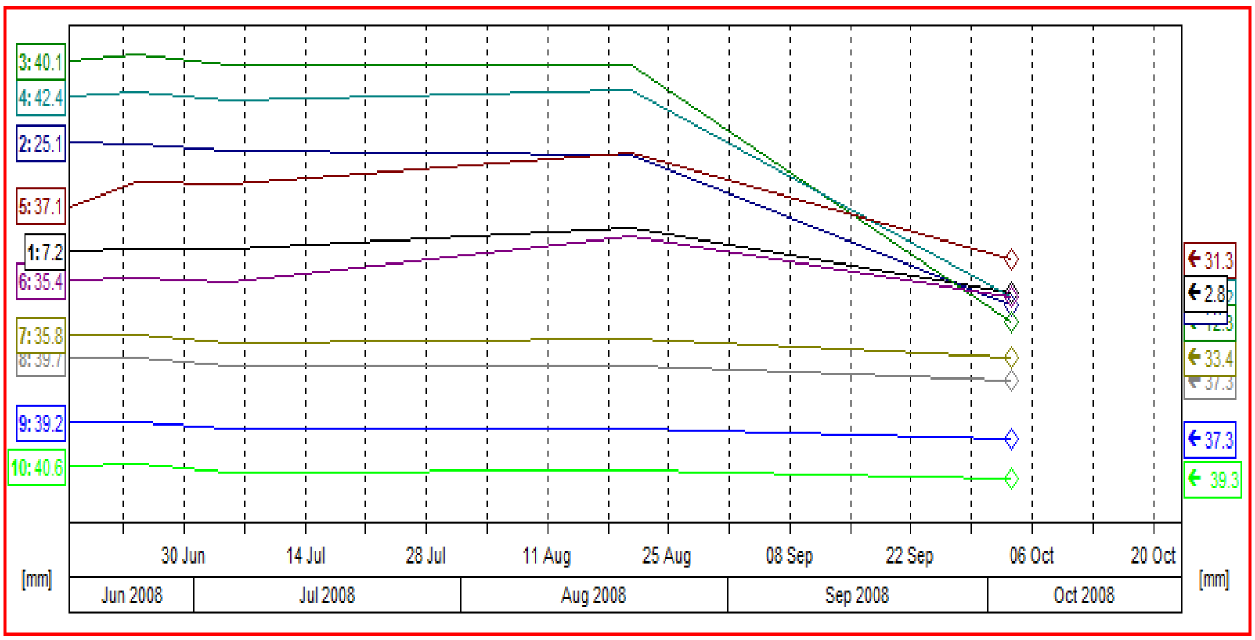
This is in contrast to CTF. Here all the background noise is removed. Everything is aligned and things that were not visible previously start to become apparent as they are replicated exactly over the field. Residue management, fertiliser applications, planter rows etc all show up any variability along the crop rows if there has been a problem.

By analysing crop yields on a row by row basis, Clay has quantified exactly the impact of wheelings in rows that are in a wheeling and rows adjacent to wheelings compared to the rest. (See Strip Intercropping page 44 for details).

2.14 Quantifying the benefits – Soil water movement

In association with the Victoria No-till Farmers Association (VNTFA), agronomist Andrew Newell has been monitoring the movement of soil moisture in broadacre crops to try and quantify some of the benefits of CTF.

Soil moisture probes are inserted into the ground 10cm,20cm,30cm,50cm,70cm and 100cm deep. The soil water content is then measured over time and plotted on a graph. Measured rainfall can then be compared to how far it gets down the soil profile and how much moisture the crop is taking out of the ground.



The above graph shows a barley field in Victoria 2008. Soil moisture is measured at ten depths on the x-axis. There is little or no rainfall as surface moisture remains static. By August the crop is starting to draw moisture form the top half of the profile. However the moisture in the lower portion remains unused, suggesting poor rooting or salinity. Source A.Newell (NEWAG Consulting)

This could prove to be an incredibly valuable technique for producing yield forecasts. As fertiliser recommendations, especially nitrogen are based on yield potential, this could help avoid much over fertilising. It is also capable of giving a recovery rate for applied nutrients based on rooting depth. We currently assume oilseed rape can utilise 60% of applied nitrogen, but this must vary substantially. Additionally it is known that nitrate nitrogen can move 1cm per day down the soil profile in the presence of sufficient moisture. This would provide a way of tracking this movement and also knowing when it is out of reach by the plant roots.

2.15 CTF Summary

The main driver for CTF is the improvement it brings to soil structure. This allows plants to root and access more of the available nutrients in the soil and with this comes an improved yield.

Allied to this is the consequential reduction in cultivations that are achieved. If the transition can successfully be made to zero tillage, then the savings are potentially significant. Machinery requirement is reduced, as is fuel usage and labour requirement. It is an option to use CTS as part of a conventional tillage system although it is unlikely that the full potential benefits will be realised.

Over the longer term the level of biological activity will rise within the soil and it will become more effective at cycling nutrients and these will become more readily available to subsequent crops. Again this should lead to a lower requirement for additional fertilisers.

Getting the correct configuration of machinery is one of the biggest challenges. It is likely that most primary pieces of equipment would have to be purchased to suit the new system and this is unlikely to happen all at once. There would most likely be a transition phase over a number of years.

In the UK, field shape and size will have a bearing on the feasibility of this system. Once put in place, it is generally a long term decision and therefore needs to be well planned.

Wider track widths may pose an issue for road transport in the UK. Some sprayers already have hydraulically adjustable axles, so it is not inconceivable that these could be adapted further,

Residue levels from previous crops are also much higher here and it would be a much greater challenge to direct seed into it. This could be overcome to an extent by choice of crop rotation.

Lodged crops at harvest can also require harvesting to be done at an optimum direction which may not correspond to the tramlines. This therefore becomes a management issue in terms of varietal selection, seed rate and growth regulator selection.

Improved soil permeability to water can help reduce soil erosion and run-off of nutrients. Given increasing UK legislation to manage soils this could be a way forward in some difficult situations.

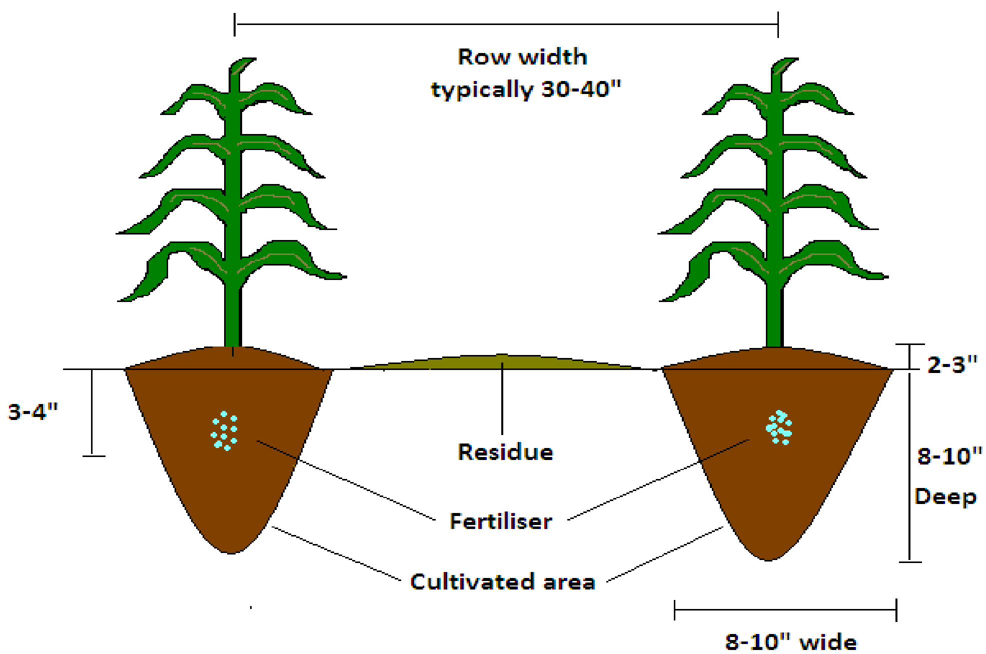
Monitoring of soil moisture has moved from irrigated horticulture into combinable crop systems. This could be effectively used to help forecast yield potential and produce more accurate fertiliser recommendations.

Various farmers are already experimenting with CTF in the UK. Tim Chamen and his colleagues at CTF Europe are also doing a lot of work to promote and develop the concept.

3. STRIP TILLAGE

3.1 What is it?

Strip tillage (also known as conservation tillage) is a cultivation system practised by North American row crop producers. It combines the soil drying and warming benefits of conventional tillage with the soil-protecting advantages of no-till by cultivating only the portion of the soil that is to contain the seed row. It is effectively a method of cultivating only a band of soil along a row into which the seeds will be planted. Row widths are typically 30 inch centres and each band is 8 to 10 inches wide. Cultivation depth can range from a shallow 2-3 inches to 16 inches.



The diagram shows a typical strip till configuration. 8-10" slightly raised bands, 30-40" apart with residue in between. Fertiliser is banded 3-4" deep directly below the seed.

The full depth of the soil profile is cultivated in the row to enable the plants to develop a better root structure. It is used in preference to min-till or no-till in poorly drained soils to allow better drainage and less waterlogging. The system is a combined cultivation and precision fertiliser placement system. According to Dr Mark Hanna at the Iowa State University, it has evolved from the practise of ridge tilling maize in the 1970s. This practice did not persist due to problems with track widths and rough headlands.

A primary cultivation is done in the autumn and fertiliser is applied at the same time. The strip will have a slightly ridged and rough finish and frost will weather the surface over winter. N, P and K fertilisers can be applied at the same time or at planting. Soils need to be 10 degrees F or less before application to ensure no mineralisation of the nitrogen occurs over winter. There is increasing pressure on US growers to apply nitrogen in the spring instead of in the autumn when 75-100% is typically applied. The reason growers are reluctant to change is due to a high spring workload with heavy reliance on a limited amount of predominantly family labour.

3.2 Strip till benefits

Soil temperatures in the strips are found to be several degrees warmer in the spring than to the sides. The dark soil of the exposed strip warms up faster and soil temperatures are typically several degrees warmer in the planting zone than between the rows. At more Northern latitudes this is of great significance as it can allow a maize crop to be established earlier and thus facilitates the 180 day growing season that it requires.

The strips are free of residue as row clearing devices are employed on the strip till rig to push trash to the sides of the rows. Another advantage is the relative firmness of the ground between the rows that allows for better weight carrying of cultivator, planter and sprayer in the spring.

The strips may or may not be cultivated again in the spring prior to planting. Grain maize is very susceptible to variations in planting depth and ¼ of an inch variation over 1 ½ inches in depth will lead to germination problems. A good finish is therefore very important prior to planting. One pass cultivation and planting systems are available from manufacturers such as Orthman, but will require the correct soil type to be effective.

By not disturbing the full soil profile this will have other benefits. Less weeds will germinate between the rows requiring less herbicide. This also gives the option of band spraying either the crop or the area between the crop, again reducing the quantity of chemical required. Reducing the amount of soil being moved has also reduced the number of passes being made across the field. In many situations, producers moving from conventional tillage to strip till have found a reduction by as many as four trips across the field.

3.3 Precision banding of fertiliser

The main appeal of the system is that the recovery rate of the precision placed fertiliser by the crop is increased compared to less accurate banding and to a greater extent surface spreading. Most growers cite a 25% reduction in P and K rates when using the system. But it has to be accurate. The fertiliser needs to be 5cm below and 5 cm to the side of the seed. Directly underneath the seed it needs to be 7-8cm. Any closer and the seed will be damaged by the fertiliser, especially at higher rates. If it is any further away the benefits of the system will be lost. The proportion of the fertiliser that is accessed and utilised by the plant is increased, meaning a lower rate can be used.

US farmer Dennis Smith of SmithChild Farms, Ames believes there are two factors that have driven the uptake of strip tillage - RTK and the price of fertiliser. RTK allows the repeatability and accuracy that the system requires. Savings from less fertiliser and fewer cultivations then more than pay for the capital investment required.

Soya beans growing in between the previous season's corn rows.

The rows have been strip tilled in the autumn and planted the following spring using RTK.

Location: Minnesota USA

3.4 Soil conservation

This system is also called conservation tillage due to the environmental benefits conveyed to the soil. Min-till and no-till play a massive role in stabilising some of the very fragile and erosion prone soils of North America.

Maintaining a higher level of soil organic matter and especially root mass is important to not only bind the soils together physically, but also to increase the water holding capacity within it. Min till and no-till have long been recognised for these benefits, but it is not appropriate on some of the poorer draining American and Canadian soils. For this reason strip tillage is finding an increasing number of users who are benefiting from a compromise between conventional tillage and zero tillage. (See appendix page 53).

3.5 Machinery manufacturers

Strip till is still in its relative infancy with an estimated 10-20 % of US crops produced using this system. More and more manufacturers are now producing the specialist equipment with Case and John Deere two of the more recent. Other producers include Dawn, Yetter, Orthman, Environmental Tillage Systems (ETS), Redball and DMI.

3.6 Machine configurations

The strip till unit is essentially comprised of a number of individual row units mounted on a toolbar. The row units can all float independently to follow terrain and to apply varying amounts of downward pressure to suit different soil types. The number of row units will correspond to planter widths and will typically range from 6 to 24 rows. Multiple configurations of row unit are available to suit soil type, residue type, residue level, cultivation depth and moisture.

A usual configuration would be a disc opener to fracture the soil and cut residue in half, a pair of trash clearing wheels to push the residue to the side, a variable depth cultivating shank incorporating a fertiliser placement device and a pair of row closing discs or rolling basket.

Yetter 8 row strip-till unit with disc opener, trash clearing wheels, fertiliser shank and closing discs.

These configurations are varied to suit soil type and conditions.

An alternative to this type of configuration is offered by Environmental Tillage Systems of Minnesota. Developed by farmer Mark Bauer, the Soil Warrior concept uses a lugged digging wheel instead of a shank to create the soil disturbance. With this system the residue on the soil surface is incorporated into the trench rather than being moved to the side.

Soil Warrior strip till unit.

Note the twin product dry fertiliser tank. This can be interchanged with a liquid fertiliser tank.

Mark feels that this is a more efficient way of recycling valuable organic matter into the profile rather than leaving it on the surface to oxidise and be lost to the atmosphere as CO_2. The wheel also creates a vertical heave of the soil rather than a more usual horizontal force that a tine will incur. This fissures the soil and leaves a more gradual transition between the tilled zone and the inter-row area. This gives better soil permeability to water and reduces the risk of zone washout on sloping ground.

The Soil Warrior can be used to apply solid and liquid fertiliser. The large primary cultivation disc can also be replaced with two smaller fluted discs and the unit can then be used as a cultivator in the spring.

Rows cultivate with Soil Warrior strip till unit into heavy maize residues. Base fertiliser is applied at this timing.

These rows will be left to weather over winter and then be cultivated again in the spring before planting.

Other than the planting, it is all done with one machine.

3.7 Implement Steering

Orthman strip till machine with True Tracker implement steering.

The pair of large discs in the centre of the picture dig into the ground and are turned hydraulically.

A second GPS receiver is mounted directly above.

Slopes can produce problems as implements do not always track a tractor exactly and will slide down hill. Systems have now been developed to put a second GPS receiver on the implement to steer it separately. Orthman manufacturing in the USA employ a pair of large discs to steer the implement. In this way it is possible to position the seed in the spring, directly above where the fertiliser is placed in the autumn, regardless of topography.

3.8 Environmental benefits

Cultivating less soil results in lower CO_2 emissions from the soil and potentially also nitrous oxide emissions will be lower. More soil organic matter will be retained to further improve soil structure. Fuel use will be lower due to decreased passes. Soil water infiltration is improved and the mulch layer and retained root mass will assist in soil stability and reduce soil erosion. Relative recovery of nutrients is improved and consequential rate reductions have both economical and environmental value.

3.9 UK suitability

Many UK farmers currently establish crops of oilseed rape using a till seeding technique. One popular choice is to mount a seeder on a subsoiler and broadcast seed behind the legs. This has proven to be a very low cost and effective means of establishing the crop. It also resembles a very rudimentary form of strip till. Various elements of the North American system could be added to this approach to refine it.

For example the trash clearing row devices could be employed to remove the need to bale straw preceeding OSR. This is often only done to make seedbeds less conducive to slugs and given the present value of the P and K in the straw it makes sense to retain the straw if at all possible. In row banding of starter fertilisers is something that is starting to happen and can also be further refined.

Oilseed rape is not usually grown on such wide row spacings but it is an option. Other crops that would be suitable for strip till are field beans, sugar beet and maize. The cultivations could be done either autumn or spring depending on soil type and also in conjunction with a cover crop if necessary. Given the present suggestions by Defra on the need for an over winter cover crop before any spring sown crop, strip till could provide a viable alternative.

4. FARMING ACCURATELY

In the case of seed, fertiliser and chemical, this is the science of putting the right amount, of the right product, in the right place, at the right time.

4.1 Precision agriculture (PA)

PA has revolutionised the way we operate. GPS guidance and autosteer systems can generate significant savings in crop inputs, fuel and associated emissions. Avoiding unnecessary overlaps during fieldwork is perhaps the quickest and easiest way to improve efficiency.

PA also opens up a mass of alternatives regarding sampling, mapping, sensing and site specific applications. If used correctly they have the potential to improve efficiency. However much of this is data generating. Before PA, the agronomic decision making process was quite simple - look, decide, do. Now the looking element can be done remotely via satellite, aircraft or with real time sensors and data loggers in field. The spatial information gathered then requires interpreting into a meaningful and useable form. Systems such as the Yara N sensor will do all of these steps automatically. However there will always be a set of assumptions that needs to be made, even in the case of the fully integrated systems.

One pitfall with PA can be to generate data and do nothing with it. Yield maps are a classic example. Unless these are used for some purpose we are in danger of simply creating more expensive ways of what we were doing before.

4.2 Yield potential

Once the fundamentals of soil structure and cultivations have been dealt with the next phase of growing a crop is to ensure that inputs are selected and used in the optimum way. Seed, fertiliser and chemical are used to remove constraints that would otherwise limit yield. In strict economic terms we should keep applying up to the point where the marginal cost of a unit of input is equal to the marginal revenue achieved. The difficulty in practise is predicting yield potential.

4.3 Management Zones

One way to improve the targeting of inputs is to split fields into management zones according to the inherent variability. It may be surprising but US, Canadian and Australian proponents of the system usually find that as few as three zones per field is adequate, with a maximum of six. This applies to small and large fields.

Too many zones and things become unnecessarily complicated. Additionally the actual in field applications will become less accurate due to the transition between zones not being 100% correct. There are different schools of thought on how to best go about determining management zones. They do however have one thing in common in that they utilise the other components of precision farming systems such as yield maps.

4.4 Soil type and management zones

The Australian Centre for Precision Agriculture base their management zones on three criteria: Soil EC maps, yield maps and elevation maps. To sample every hectare and conduct a full soil analysis would be prohibitively expensive so instead they use other criteria and then corroborate this with yield information.

Brett Wheelan explained that from the soil electrical conductivity (EC) and elevation maps it is possible to identify soil type. This in turn is sampled by zone to give nutrient and pH levels. It also provides information on soil depth which provides an estimate of moisture holding capability and therefore yield potential. From these two items an overall map of yield potential can be established and the crop can then be seeded and fertilised accordingly. The prescriptive seed rate and NPK maps are generated on the back of this information.

Yield maps are then used for two things. Firstly to corroborate that the yield potential assumptions were correct. Any areas performing under expectation are then soil sampled to find out the cause. Secondly the yield map also provides nutrient offtake data that can then be incorporated into the following season's recommendations.

4.5 Satellite imagery and management zones

Canadian consultancy firm Farmer's Edge agronomy started offering variable rate fertiliser recommendations 7 years ago. This year they expect to make recommendations on around 1 million acres in Canada.

This is based on a very simple concept using satellite crop imagery from a 10 year database of fields. The underlying assumption is that an NDVI (Normalised Difference Vegetation Index) image showing crop biomass before harvest will give a good indication of yield. In the absence of a yield map this is the next best thing and gives a good indication of yield potential and by inference soil type. An advisor will then sit down with a grower and select maps from fields of previous season's crops that appear to be representative of that field. Using specialist software, this imagery is then converted into approximately five management zones. The zones will then be soil sampled according to these zones and a prescriptive fertiliser recommendation generated from it.

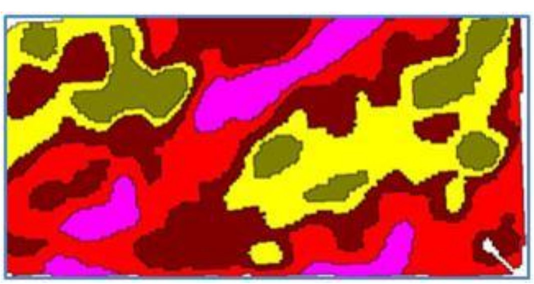
Possibly the most significant factor that emerges consistently from the soil sampling is that the highest yielding areas have the highest levels of soil organic matter and therefore nitrogen. It is these areas that can receive less nitrogen in future and still maintain the yield

The table overleaf shows the results for a field that has been split into 5 management zones and soil sampled according to these zones. According to consultant Steve Larocque there is a correlation between high organic matter levels in the soil samples and the high NVDI levels on the satellite imagery. Yield can sometimes actually be slightly lower in these areas due to the extra fertility causing lodging before harvest.

Field	Acres	%OM	pH	N	P	K	S
Zone 1	10	1.3	5.7	42	98	413	16
Zone 2	24	3.4	6	36	60	853	41
Zone 3	25	5	5.7	60	91	829	42
Zone 4	18	5	5.9	31	86	732	135
Zone 5	8	6.9	6.1	249	161	1079	106

The table below shows the VR fertiliser recommendation in comparison to a conventional management approach using one flat rate of fertiliser. The predicted value of the VR application through increased yield has also been estimated.

NAME	NEUFAR		46-0-0	11-52-0	0-0-62	21-0-0-24
FIELD	NE 18-29-25-W4		Conventional Management			
CROP	WHEAT- HARVEST		75	0	30	0
Conv. Average bu/acre		65	N	P	K	S
ZONE	YIELD	ACRES	Zone Management			
Zone 1	35	9	45	0	0	0
Zone 2	55	24	71	0	0	0
Zone 3	70	25	80	0	30	0
Zone 4	85	18	96	0	40	0
Zone 5	85	8	0	0	45	0
Total Acres		84				
Averages	67		69	0	21	0
Commodity Price		$ 6.00	VR Yield Value			$ 8.84



On the left is a map of the field showing the location of the five management zones.
This can then be modified to produce a prescriptive map to use in a VR controller to apply the products.

Source: Steve Larocque, Beyond Agronomy

4.6 Topography and management zones

Canadian producer Jim Robins of Blackie, AB has been seeding using a RTK based variable rate system he built himself in the early 1990s. The gently rolling fields of his Alberta farm were split into upper, mid and lower slopes. Yield potential was found to correlate directly to these areas due to the movement of water and nutrients across them.The most fertile are the lower lying areas and the least the upper slopes. The fields were mapped for elevation using RTK and it quickly became apparent that only these three zones across the whole farm were necessary.

Soils are sampled according to these zones and the bulk of fertiliser is applied at sowing using a Bourghault grain cart which has 5 hoppers for different materials.

4.7 Variable Rate and Carbon

It has been estimated that on an average field one third of the area is over fertilised, one third under fertilised and one third receives the correct amount.

Farmers Edge Agronomy are currently seeking to form a carbon protocol for using VRA technology to reduce GHG emissions. By removing the over fertilised areas this will reduce the amount of nitrous oxide and CO_2 being released as a consequence. Yield should also be increased by a relative proportion. Given their extensive database formed from the recommendations, accruing the necessary data required as a carbon aggregator will be relatively straightforward and profitable.

Carbon dioxide equivalence (CO_2e) is a way of converting six greenhouse gases into a single metric, in terms of their global warming potential. Nitrous oxide from nitrogen fertiliser is 300 times more damaging than CO_2. For this reason a small reduction in nitrogen usage will have a massive impact on our on farm environmental profiles.

4.8 Variable Rate Trials

One of the greatest impediments to proving the benefits of variable rate applications is that it is not possible to replicate a VRA trial.

The answer is to implement control strips within fields. These can be done in individual crops or in the case of controlled traffic systems can be done every year in exactly the same place. The advantage here is that it allows precise monitoring of yields, applications and offtake to ensure that everything is happening as expected.

Users of the Greenseeker crop sensing system will fertilise a nitrogen rich strip within a crop and an unfertilised strip to provide relative information upon which to base nitrogen applications. These can then be yield mapped to determine whether nitrogen was a yield limiting factor on the rest of the crop. Richard Heath who farms on the Liverpool plains in Australia has been pleased with his experience of the system and has successfully reduced nitrogen use on his crops without compromising yield.

4.9 Variable Rate limitations

An alarming conversation with Professor Matt Darr at Iowa State University revealed that even brand new and tested machinery may not actually place material where it is meant to go. Having tested a range of new fertiliser spreaders from various manufacturers it was clearly established that using a machine calibrated at a set rate and speed does not automatically mean that this machine will be capable of holding a spread pattern at another rate and/or speed. In fact the differences can be alarming leading to massive variances in distribution even though it has been properly calibrated.

There are also lag times and delays with hardware not responding as quickly as anticipated, even though lead times have been programmed into the controllers. The result is right product, wrong rate and wrong place with more variability introduced.

4.10 Protein Sensors

Protein sensors are also being employed to provide further clarification of nutrient offtake and also to validate yield potential. We currently assume that low protein means a crop has been under fertilised and vice versa. However use of the protein sensor has not fully confirmed this and other factors have been found to have an influence on grain protein. Trials with trace elements such as zinc have increased protein levels by 1%.

Several makes of protein sensor are currently available. They are both expensive and difficult to calibrate especially when grain has suffered weather damage according to Australian grower James Hassall. The sensors use an optical element and variations in grain condition and appearance impact on the calibrations.

4.11 Linear applications

VR has the capability to reduce input use on a block by block basis. However, the Australians are using an old technology in the form of band spraying to very successfully reduce input usage on a row by row basis. Shielded sprayers are being used to apply non selective herbicides to non herbicide tolerant crops of oilseed rape and field beans. Using GPS guidance means that this is now much quicker and more accurate than in the past. More importantly, chemical usage is slashed by up to 70%. Not only can herbicides be sprayed between the crop rows, but using a twin tank machine, fungicides and insecticides can be applied to the crop rows at the same time. A band sprayer has even been developed to use in cereal crops sown on 15” row spacings

Taking this one step further, Australians such as Robert Ruwoldt have modified the nozzle spacings on their sprayers to correspond exactly with the row spacing of the crops being sprayed. High accuracy controlled traffic systems mean that when multiple planter widths are being sprayed with one pass of the sprayer, everything still matches up. In this way it is possible to insert blank nozzles wherever no chemical is required. For fungicides and insecticides the areas between the crop rows would be blanked off. For herbicides the area above the rows blanked. In this way it is possible to save up to 60% on chemical whilst still maintaining dose rates. Drop legs can also be used to increase penetration of the crop should the need arise. This technology has been used for some time in the cotton growing areas and has now been adapted to other crops grown on wider rows.

Inter row spraying field beans using a shielded spray with a non selective herbicide.

High accuracy GPS steering systems make this much easier, safer and faster than before.

Sprayer nozzles spaced to exactly match row width. Inputs can then be targeted to hit either the crop, or the area between the rows.

Source: R.Ruwoldt

Another concept that has been developed by Australian growers when harvesting is to minimize the return of weed seeds to the following crop. The combine is fitted with a cyclone to collect the chaff coming over the sieves. This is then laid, in a row, in the controlled traffic wheelings. In the case of rye-grass, which is a massive problem, it means that weed seeds are confined to a strip along the field instead of being spread all over the field. In the subsequent crop, this strip can then be sprayed out using a non selective herbicide for total control.

Combine with cyclone attached to collect and lay chaff and weed seeds in one wheeling.

In the case of ryegrass this can then be sprayed out in the subsequent crop using a non selective herbicide.

Sprayer being used to spray rye-grass in tramlines.

The amount of chemical being used is massively reduced.

Additionally the selection pressure on the selective herbicides used on the rest of the field is dramatically reduced.

Source: WANTFA

4.12 Spray application technology

Nufarm Australia have directed a lot of energy into educating growers on how to maximise spray application effectiveness through a series of interactive spray workshops. In the cotton and sorghum growing areas of southern Queensland, spray drift is a massive problem. Not only can crops be killed by herbicides that are volatolised and carried miles before descending on neighbouring crops with disastrous consequences, but cotton insecticides can also contaminate sorghum crops pre harvest leading to rejection at the point of intake.

Spray quality is influenced by four factors – nozzle type, pressure, formulation and adjuvants. The first two are the most commonly recognised but the latter pair less so. The product formulation and use of an adjuvant may cause the production of more or less drift by altering the size of the 'sheet' that is produced by a nozzle. The sheet is the area directly below the nozzle that appears as a continuous film of liquid. The larger the sheet, the greater the drift. If the sheet can be broken up more quickly after leaving the nozzle then it will produce less fine particles and therefore less drift. The choice of formulation may be predetermined by the product being used but an adjuvant may be used that can improve the characteristic of the nozzle pattern. Conversely it can also make it worse.

To illustrate this Nufarm demonstrated on a static spray boom how to manipulate spray quality through the use of adjuvants. The next phase of the demonstration was to illustrate the impact of nozzle choice. A mixture of an ultraviolet tracer dye and water was sprayed onto a crop of cotton and adjacent fallow land that was covered with a senesced cereal cover crop. A spray plane, Spra-coupe sprayer with four different sets of nozzles on each quarter of the boom and a Weed-Seeker all sprayed plots with a buffer area in between.

Spray plane applying a UV tracer dye as part of a demonstration to evaluate spray quality.

On returning to the plots after night fall it was possible to see the difference in application using hand held black light torches. Every droplet becomes visible and it is possible to see droplet size, coverage, penetration and density. Additionally it is also possible to see any coverage of non sprayed adjacent areas through spray drift. Conventional XR03 flat fan nozzles produced by far the most drift and are widely considered to be the root of all evil in this area. Air induction nozzles provide much less drift with comparable levels of coverage and penetration.

Using a blacklight torch, it is possible to see spray deposition.

Droplet size, canopy penetration and coverage is all visible to the naked eye.

Also visible is any spray drift to non target areas.

By far the most impressive was the Weedseeker. Operating at a relatively 'slow' 25km/hour compared to the 30 km/h Spra coupe, it hit every single bit of greenery that was present in the fallow area without over or under spraying.

Weedseeker sprayer operating in fallows.

These machines will typically apply 3-20% of a total field area when applying non selective herbicides to fallow fields and are widely recognised to be the fastest repaying machines on many Australian farms despite the high capital cost of around £1000 per metre.

The large move to controlled traffic and zero tillage means that weed control in summer fallows is a major part of the seasonal workload and they may be sprayed 4 or 5 times to keep on top of weeds and residues before the following crop is sown. As an alternative to a consecutive blanket sprays the savings are enormous.

5. BIO-AGTIVE EXHAUST GAS FERTILISER

7.1 What is it?

Alberta farmer Gary Lewis has developed a system to cool and inject tractor exhaust gases into the soil when planting with a pneumatic seeder. The system is licensed and marketed through his company NC Quest. The name is to reflect the significance of the Nitrogen/Carbon balance in the soil.

5.2 What are the benefits?

Not only does this reduce exhaust emissions to the atmosphere, but it also supposedly causes an interaction with soil bacteria and stimulates root growth. The net effect is a reduction in fertiliser requirement for all major nutrients. Some Canadian farmers have actually moved to zero applied fertiliser in conjunction with using the NC Quest system. This reduction in fertiliser use and associated transport gives a further reduction in greenhouse gas emissions.

Having initially spent 7-8 years tinkering with a pump on a centre pivot irrigator and mixing the exhaust with the water, Mr Lewis found that he was able to get an extra crop of timothy per year from the irrigated pasture according to Jerry Stinson an owner and operator of the system in Bowsman, Manitoba. This experiment led to the tractor mounted variant being developed.

5.3 How does it work ?

Exhaust contains heat, water vapour, trace elements, carbon dioxide which is an essential component to plant life and nitrous oxides (NO_2, NO_3),which are highly beneficial to soil microbes.

Exhaust gas being incorporated in the ground at seeding time.

Pipework takes the exhaust gases from the tractor exhaust and through a series of pipes to cool it before passing through the air seeder and into the ground.

5.4 Equipment

The equipment consists of a pipework running from the tractor exhaust to collect, cool and inject the gases into the ground. Original units such as the ones pictured above, relied on large diameter aluminium pipes to provide enough surface area to effect the cooling process. If the gases were still too hot the engine could be slowed down or a flap could be opened to release a proportion of the gases out of the system. Exhaust will usually be coming out of the tractor at around 200 degrees F and need to be cooled to 100 degrees F. The main reason for necessitating the cooling is to avoid melting the plastic air pipes on the seeder unit.

The design has now been changed to use a smaller cooling system incorporating a fan that produces a neater installation. Leicestershire contractor Steve Heard, a pioneer user of the system in the UK in 2008, has installed a cooler on the front of the tractor. This gives added versatility in the range of implements that can be used for incorporation. Given that heavy land UK growers are typically using 60 litres per ha of fuel for crop establishment, this is 4-5 times more useable exhaust 'fertiliser' than a typical one pass Canadian prairie system.

5.5 System costs

The equipment costs around £10,000, with a one off £5000 technology user fee. An annual £500 year license fee then applies. There are currently 110 licensees globally in Canada, USA, Australia, South Africa,UK and most recently Japan. 75% are in Canada and 15-20% in the US.

5.6 User comments

Jerry Stinson has used the system for 2 years and now applies no fertiliser to wheat and canola. 2008 was a bumper harvest in his area with wheat averaging 50-55 bushels per acre and canola 35-40 bushels per acre. His own wheat crops yielded 32 bushels and canola 24 bushels. This equates to a revenue loss of 3 times the cost saving in fertiliser. Despite this Jerry felt that this translated into other benefits. He did not have to sell any grain forward to cover expensive fertiliser bills and there were also savings on grain and fertiliser haulage. In a dry year he felt the difference would be less and his exposure to risk would also be lowered by not having as much working capital tied up in the crop in the event of a poor harvest or a complete crop failure.

In the previous year Jerry experimented and could see no difference between areas that had exhaust applied and not applied. This year he will be attempting to put the exhaust deeper into the soil to try and stop escape of the gases especially in dry and windy conditions. NC quest are also in the process of conducting their own trials and according to Dr Dave Balfour they are currently in the process of assimilating data. Unfortunately one of the trials this year was hit by hail and ruined. His feeling was that 'science lags innovation at times' and this applied to the lack of clear understanding of exactly how or why the system works.

Another user of the system, Lyall Johnson of Windhorst SK also cut back on fertiliser last year in conjunction with incorporating exhaust gases. 'I didn't use any fertiliser last year and was disappointed. We should really have used half rate. It wasn't as good as they thought'

Robert Stewart,a farmer located at Didsbury AB has been using the system for three years and views it as a work in progress and acknowledges that there is a lot still to be learnt about the system. He feels that it will never grow as much as a fertilised crop but it is a much more sustainable approach in the long term.

Robert's most significant discovery was that multiple passes incorporating more exhaust each time resulted in a direct increase in available soil phosphate when the areas were subsequently sampled and analysed. Another observation was that crops were more prone to herbicide damage when grown using the system compared to using applied fertilisers.

Rob Olsen of Robotesting SK works on research and development of the system. He felt it had been a very positive year with growers having different approaches to the system. Full converts apply no fertiliser, some cut by half and others apply a foliar application of nitrogen. They currently do not know which type of smoke is best and fuel additives are currently being used to try and manipulate the exhaust composition to see if this makes any difference. The company is also working with Bulldog engine management systems in Idaho US to see if the emissions can be manipulated to a desirable composition electronically.

Steve Heard is in the process of conducting extensive trial work with the system at his farm in Leicestershire in conjunction with agrochemical distributors and other interested parties. Initial findings from autumn 2008 were limited although he did feel that slug numbers were lower where the system had been used. Although this was a purely anecdotal observation it could prove to be a useful side effect, even if it raises issues concerning the welfare of other soil borne organisms.

5.7 Conclusion

While there is no doubt that this is an effective means of reducing atmospheric emissions, further work needs to be done to establish if, how and why anything actually happens once the exhaust has entered the soil. There are however definite environmental savings, as users are cutting back on NPK fertilisers. This leads to less being manufactured, hauled and used – all of which are tangible and quantifiable economic and environmental savings.

A yield reduction in conjunction with the system is acceptable, assuming the net saving is greater than the net loss of output, and when combined with reduced fertiliser consumption it can only have a positive impact on the industry. If enough growers adopt this practise globally the price of wheat should go up due to reduced supply and the cost of fertiliser should come down due to decreased demand. Maybe this is the technology of the future!

6. BIOTECHNOLOGY

6.1 What is it ?

Biotechnology is another term for genetic modification (GM). It is a way of producing crops with selected characteristics through genetic manipulation rather than conventional breeding.

Biotechnology in the form of transgenic crops has been harnessed globally by growers to a very large extent. 282 million acres were planted in 2007 with 142.6 million acres in the USA alone. Nearly 90% of all US maize and soybean crops in the near future will contain the Roundup Ready (RR) herbicide tolerance gene. This was the first commercially available trait to be produced by Monsanto.

6.2 Traits

Traits are the desirable characteristic that are introduced to the host organism through biotechnology. They have now been categorised as input and output traits. Input traits are those involved with the production side of the crop and typically convey a benefit to the producer. Output traits are becoming more common. These are traits which offer a benefit to the consumer. Modified vegetable oils with an improved Omega 3 content and high oleic/low linoleic oils would be examples of this.

6.3 Germplasm

This is essentially the seed into which the trait is introduced. Potentially any variety of a crop can have the desirable trait introduced to it. Conventional breeding can sometimes be a more effective way of producing a desirable characteristic. For example resistance to clubroot in oilseed rape is being developed conventionally in preference to using biotechnology. Advances are therefore being made in two ways, and can be put together to give a result that exceeds the capabilities of the two methods individually.

6.4 Herbicide tolerance

Herbicide tolerance (HT) to non selective herbicides was the first product brought to market by Monsanto in 1995. The trait allows the host crop to be sprayed with glyphosate (Roundup) herbicide for both annual and perennial weed control. In the absence of the tolerance gene, this would normally kill the both the weeds and the crop. The advantage is that the overall herbicide programme within the transgenic crop is greatly reduced by using one or two relatively low doses of a herbicide with a good environmental profile versus numerous non selective herbicides in a conventional programme. The overall loading of herbicide entering the environment and potential non-target areas such as water is greatly reduced.

Additional benefits coming from herbicide tolerance would be that the number of passes required with the sprayer in a crop is reduced, giving a consequential saving in labour, machine hours, fuel and chemical. Reduced chemical volume being used also reduces the quantity of operator exposure to chemicals by reducing overall exposure time.

6.5 Non selective herbicide resistance

Given the vast acreages that are being sprayed with Roundup annually on transgenic crops, the selection pressure for herbicide resistance is potentially large. This will be more so in winter sown crops than spring crops. The reason for this is that there is greater opportunity for cultural weed control by alternative methods such as cultivation preceding a spring crop. This acts to break some of the chemical burden by removing autumn germinating weeds and will tend to select more for spring germinating annuals. An approach being used by US growers as part of a strategy of stewardship to manage herbicide resistance is to apply a low dose of a residual herbicide to stubbles in the autumn on ground that is to be no-tilled the following spring. Atrazine and simazine would be popular choices.

An alternative approach that will be marketed in 2009 involves the use of different modes of herbicide tolerance within the crop itself. Another trait is introduced, this time tolerance to glufosinate ammonium which is the Liberty Link trait belonging to Syngenta. This means the crop can be sprayed with one or two different non selective herbicides with the aim of decreasing selection pressure on one particular herbicide. This method of introducing multiple traits within one variety is called gene stacking.

6.6 Gene stacking

Developments in technology have facilitated the addition of multiple traits within a variety. Single stack genes such as Roundup Ready (RR) have given way to Triple stacked varieties. An eight way stack (Smart Stax) is due to be launched by Monsanto in 2009. The US Environment Protection Authority (EPA) has given clearance for this in cotton and other crops are expecting approval shortly.

Vectron technology (VT) allows multiple genes to be inserted into the modified plant at once. The gene bundle is described as a ‘cassette’ which is inserted into the plant DNA. The location of this gene bundle along the length of the DNA has recently been found to influence other characteristics. A repositioning of the original RR trait has been found to increase yield in soya beans.

Insecticidal properties are derived from proteins produced by the plant. A total of five proteins will cover above and below ground pests. Two more infer herbicide tolerance to Roundup and Challenge and a final trait will give yield enhancement. The multiple genes for insect pests are part of a programme to manage resistance to single gene traits.

6.7 Insecticide resistance management

As with any artificial control measure, if it is reliant on a single mode of action, the chance of selection of resistant types is significantly increased. Multiple genes against the same target organism have therefore been introduced.

Currently where insecticidal traits are used, producers have to leave an area of the field or farm equivalent to 20% of the total area being sown, to crop that does not have these traits. These areas are called a ‘refuge’. The idea is that non resistant insect types will occur in these areas and maintain a level of susceptibility within the overall population. The refuge area can be sown with a single gene, herbicide tolerant variety.

The advent of eight way trait products with multiple insecticidal traits has seen this refuge area requirement being reduced from 20% to 5%. This represents a significant market share increase for more expensive seed trait packages.

6.8 How is it done?

Inserting a gene into a plant's DNA is easier said than done, although today it has become much better understood.

Originally the process of putting genes into DNA was done using a 'gene gun' (Biolistic Particle Delivery System), which fired a pellet coated with the new gene and gold particles at a piece of plant tissue. The genes would pass through the tissue and some would invariably lodge in the DNA of the individual cells. However this was a very hit and miss affair which has subsequently been replaced by bacteria (agrobacterium tumefaciens) which are now responsible for insertion of genes into DNA in a process natural to themselves. The agrobacterium is used to integrate a segment of its own DNA into the chromosomal DNA of its host plant cells.

An impregnated cell is then taken and multiplied up to produce identical replicates. Once a cluster of these cells is formed a plant will then regenerate itself and with the use of growth promoters and hormones, it is possible to produce a plant that has the modified DNA in 100% of its cells. This plant will then exhibit the trait which has been inserted. This is a very simplistic overview of the procedure and much screening and testing is required both before and after this process.

As each trait introduced has significant impact on the characteristics of the plant, legislation requires a thorough testing and qualification that the outcome is safe. As this is a lengthy and expensive process, the new technique of inserting multiple genes in a cassette type formation is desirable as it requires only one validation process for all the traits. This is opposed adding traits individually that each require a separate approval.

6.9 Agronomic Zone Pricing

This leads to a consequential effect on the pricing structure of these products. It is cheaper to develop a multi-stacked product in a single phase rather than doing individual additions, and additionally it is easier logistically to have a portfolio of varieties that are with or without a multiple trait stack. The number of combinations is therefore greatly reduced versus the number of varieties that could potentially have one or any multiple of traits within them. Inventory control and seed production is much simplified by this route.

However these traits do not come free! Seed is priced according to the perceived cost saving/ yield benefit to the producer, with an approximate 50:50 split. As genes are effectively removing the need for one or more application of a pesticide with a guaranteed level of efficacy, this has a direct cost saving value. It will also increase yield in the presence of a relevant pest, giving an increase in gross output.

The introduction of multi-stacked products has made seed production and registration of products quicker and cheaper, but it does lead to pricing complications. The reason is that a grower gets a full set of traits whether they are needed or not. Pricing has now been shifted to location based, risk level scenario, whereby a producer will pay more for seed if they fall into a pre-determined high risk area for a particular trait, than another grower using the same seed in a low risk area. Currently there may be up to four cost levels based on the risk location and this will increase in number and complexity as more genes are combined into a single product. It can also lead to animosity amongst growers who border each other but find themselves at opposite ends of the pricing spectrum, in which case it would be expected that the situation would be handled with a discretionary approach and potentially a level of discount to one party to form a more gradual transition between areas.

6.10 Crop insurance reduction

GM crops have proven to be a reliable means of mitigating against crop failure through better drought tolerance, a reduction in yield variability and increase in crop probability. They now qualify for a crop insurance premium reduction in the USA. It is effectively like a 'non-smoking discount on health insurance' and certainly testament to the effectiveness of the technology.

6.11 GM Crop types

Wheat was actually one of the first crops to be developed as an GM crop. However due to reluctance of a large US processor it never came to fruition, but the technology is there for a Roundup Ready wheat variety.

Corn, soybeans, cotton and canola are currently the major crops produced globally with GM traits. Approximately 120 GM traits have been authorised for use on 23 crops worldwide. Approvals for use in Europe have to be made by the European Food Safety Authority and then be sanctioned by the EU farm council. Currently there are approvals for a handful of EU member states to produce GM crops with Spain producing the majority in the form of grain maize. As this only extends to around 110,000 ha it is a negligible amount compared to production globally.

Whilst the EU seems unable to decide on how to move forward with GM, things are developing rapidly elsewhere. Fortunately winter oilseed rape is set to make large leaps forward as many conventional European lines are being collected together by Monsanto at a new breeding facility in North America to develop better hybrids and incorporate more producer and consumer traits than the current HT varieties.

Even though corn and soybeans are of little direct agronomic relevance to the UK, the fact that any identified trait can potentially be moved to alternative host species is significant. As each trait is a combination of DNA base pairs that are common to all DNA it facilitates exchange across species. It also means that developments in these crops and a consequential better understanding of the management impacts of these traits through extensive use may potentially be available in our own crop types sometime in the future.

6.12 Oilseed rape

A large play for winter oilseed rape acres is currently being made in the US in the mid-western wheat belt (primarily North and South Dakota, Kansas), which is traditionally a continuous wheat production area. By growing OSR, one year in three, this would create an additional 6-7million acres of the crop in an area that has never produced it. A further 2 million acre reduction in cotton grown in southern central US has generated more area suitable for OSR production. Large domestic demand and China being a large importer of rapeseed oil are the main drivers for demand. The ramifications are that the crop will be able to sustain significant research dollars and it will progress from where it is today to the levels where corn and soybeans are with multi stacked products. These varieties would also potentially be suitable for European use and only require registration.

In the development pipeline for OSR is Roundup Ready 2 which has a greater tolerance to glyphosate meaning higher rates and later timings can be used. Currently there is a cut off time for application of Roundup to the crop. This is because the crop is only tolerant to a finite amount of the herbicide and damage will occur if this is exceeded or the crop enters a more susceptible phase of its development. Applications at the onset of flowering and later can lead to sterile pollen. Other traits include dicamba tolerance and sulphunyl urea (SU) tolerance to assist with previous crop application issues and ultimately a full SU tolerance so the crop can receive a full SU application. Disease profiles are also set to modified with phoma stem canker and white mould being targeted. A pod shatter gene has also been identified – and some have proved so effective that it is actually impossible to open the pod!

6.13 Development payback

Growers pay an acreage license fee of around $10 per acre per year to use GM crops. Paid to the seed developer, this cost is in addition to paying for the seed. Hybrid corn varieties cannot be farm saved for seed from one year to the next. Soya beans can be saved on as they are not hybrids. This can lead to issues if it is not declared to the seed developer and the technology fee is not paid. Currently some South American growers are home saving soybean seed and are not declaring it. The incentive therefore is to produce hybrids which gets around this issue which is why the emphasis is being placed on hybrid oilseed rape varieties.

Seed biotechnology companies in the US are currently developing the role of satellite based imagery and geospatial information systems (GIS) to help identify optimum suitability for variety location and it is not inconceivable that eventually it will be possible to remotely identify GM crops from satellite imagery to help with the issue of license infringement.

6.14 Relative advantage

As OSR and pulse growers we compete head on with GM soybeans in the global proteins and vegetable oil markets. As wheat growers we compete with GM maize in the global soft grains markets.

The bad news is that as UK growers, we can't compete with this method of production any more. The break evens for GM maize and soybeans in £ per tonne are way below our own costs of production for wheat and oilseed rape.

Chemical inputs for a crop of spring sown GM corn grown on US corn belt soils will typically be two low doses of a non selective herbicide and possibly a fungicide. Nitrogen and potassium requirements are similar to a 4 tonne per acre crop of wheat, with phosphate also similar but typically found at higher levels in the soil. Most fertiliser is autumn applied with a single cultivation pass. This will yield approximately 220 bushels (6 tonne) per acre and have a similar market value to feed wheat.

Given our own crops of September sown winter wheat require 3 herbicide timing combinations (5 products), four fungicide timing combinations (up to 9 products), three growth regulator timing combinations (5 products), three insecticides, four adjuvants and a seed treatment and are in the ground for nearly 12 months and yield around 70% as much, it is not difficult to see why the contrast is so great.

The entire advantage in this example cannot be attributed to biotechnology as the soils are wonderfully deep, black and fertile and the climate provides near perfect growing conditions with deep penetrating frosts forming a good soil structure remedy and pest innoculum remover allied to plentiful growing season rainfall and high light intensity.

What cannot be avoided is that GM is making farming easier and more productive. Corn yields have risen from an average 180 bushels/acre five years ago to 250 bushels/acre and are still rising. Monsanto's aim is to double yields in the next 20 years. In the UK we have a rapidly diminishing pesticide armoury in terms of both number of products and also efficacy. The EU review of pesticide registration looks set to remove more chemistry and pressure is growing to reduce public exposure to agrochemicals in light of the recent Georgina Downs Court ruling.

Our input levels have reached saturation point as we are piling on the amount of chemistry to try and achieve the results that we want. The effectiveness of these products is diminishing, whereas GM is continuing to add another string to the bow. It makes life easier – less spraying, less hazardous material to handle, less operator exposure, less public exposure, less environmental exposure, less non target exposure. Would you rather fill up a drill with a bag of seed that contains the solutions inertly within it, downsize the sprayer, buy less fuel, pay less labour, have more time off or keep up the level of management intensity which we have got used to? This divergence will continue to grow as we strive to find ways to sort our agronomic problems and invariably will require a greater level of husbandry in the form of cultural control measures. This builds in yet more cost and if we can maintain yield we will be doing well. On the other hand, the GM camp will find more and more advantages coming their way as nitrogen efficiency reduces the need to buy and apply as much N fertiliser, drought tolerance increases yield etc. The gap is big and it is growing, this is why it is important that GM winter oilseed rape and other crops that we can use are being developed and we do not have to make a standing start in 10 years time or whenever it might be that this becomes a universally acceptable form of production in the UK.

6.15 Implications

80% of GHG emissions from the production of a crop of oilseed rape come from the associated nitrogen fertiliser manufacture and use and subsequent release of nitrous oxide. Better utilisation of nitrogen will have a massive impact on the associated carbon footprint of the crop and GM generally could play a big part in reducing overall carbon (equivalent) emissions. Current estimates suggest that a 10% nitrogen reduction in maize is possible, through a more efficient and less pest damaged root structure. In the longer term this is expected to get nearer to a 50% reduction for an equivalent yield.

HT crops have now become the norm in Northern America. The producers, suppliers and marketing channels have adapted to it over a period of time. For producers the transition is a relatively simple one, as it largely infers production efficiencies. For seed and agrochemical suppliers it can be more difficult as market share is either gained or lost. In the case of agrochemicals, they can be replaced altogether. Roundup has replaced a vast quantity of selective herbicides and now there is a vast reduction in the amount of insecticide being produced, marketed, recommended and used. The whole supply chain is gradually being reshaped and redefined. As this is a gradual process it is not overly difficult, although there will always be winners and losers. From a European perspective, if we adopt this technology in the form of developed multi-stacked varieties sometime in the future it could have a sudden and potentially quite harsh impact on certain sections of the industry if it is universally taken up by growers.

7. STRIP INTERCROPPING

7.1 What is it?

The concept of intercropping is based around more efficient utilisation of available sunlight during the crop growing season. Instead of growing the two crops one after the other, they are grown together in the same field. A 30'planter width of corn is alternated with a 30'planter width of soybeans across the whole field. In the following year the system is reversed.

12 row corn beds prior to harvest. The soybeans have already been cut.

Notice the corn plants are taller in the centre of the beds due to greater competition for light.

The shorter, outer plants are the highest yielding.

At harvest the soybeans are harvested first in September and the corn later in November. In a year where the headlands are corn, they will be planted with an early maturing variety to facilitate harvest of the remaining soybeans.

Harvesting 12 rows of grain maize (corn).

The chaser bin is running down the controlled traffic lane of a strip of soybeans that have been harvested earlier.

It is equipped with 3 metre wheel centres to match the combine and can utilise the RTK steering for unloading.

7.2 Why is it done?

Clay Mitchell is a pioneer of the system and pointed out many unexpected benefits. Firstly the light efficiency and yield is improved in the outer rows of corn. As the soybeans are less light hungry they suffer a proportionally lower decrease in yield on the more shaded side. The combined return is a net increase in gross output by around 10-15% for the same quantity of inputs. This equates to a more efficient use of sunlight.

7.3 How is it done?

Two key factors have facilitated this to be a feasible proposition. Firstly GM crops mean that the agronomy of the two crops is now very tightly aligned. The whole field is sprayed at the same time for herbicide and fungicide, with insecticide mainly taken care of by newer GM traits.

Secondly, RTK makes it possible to accurately plant one crop and return later to plant the other. Implement steering is essential to ensure that the two crop types do not overlap.

Other functional benefits are realised such as always having an area to unload when harvesting corn on long runs in high yielding crops. The strips where the soybeans have been harvested allow the chaser bin to run on the side of the combine that houses the unloading auger at all times. This avoids having to stop and unload when opening up new lands. Spraying is also aided as instead of having to count 'guess rows', it is possible to turn directly into the centre of next swath without having to firstly estimate where to drive. Later maturing corn crops also dry out quicker as the wind can more readily penetrate the canopy. Clay originally felt this could also be a weakness and lead to more lodged crops, but this has not materialised, possibly due to greater lignification of the outer rows. The downsides are having twice as many moves when performing field operations and greater capital requirements in the form of more sophisticated guidance and implement steering systems.

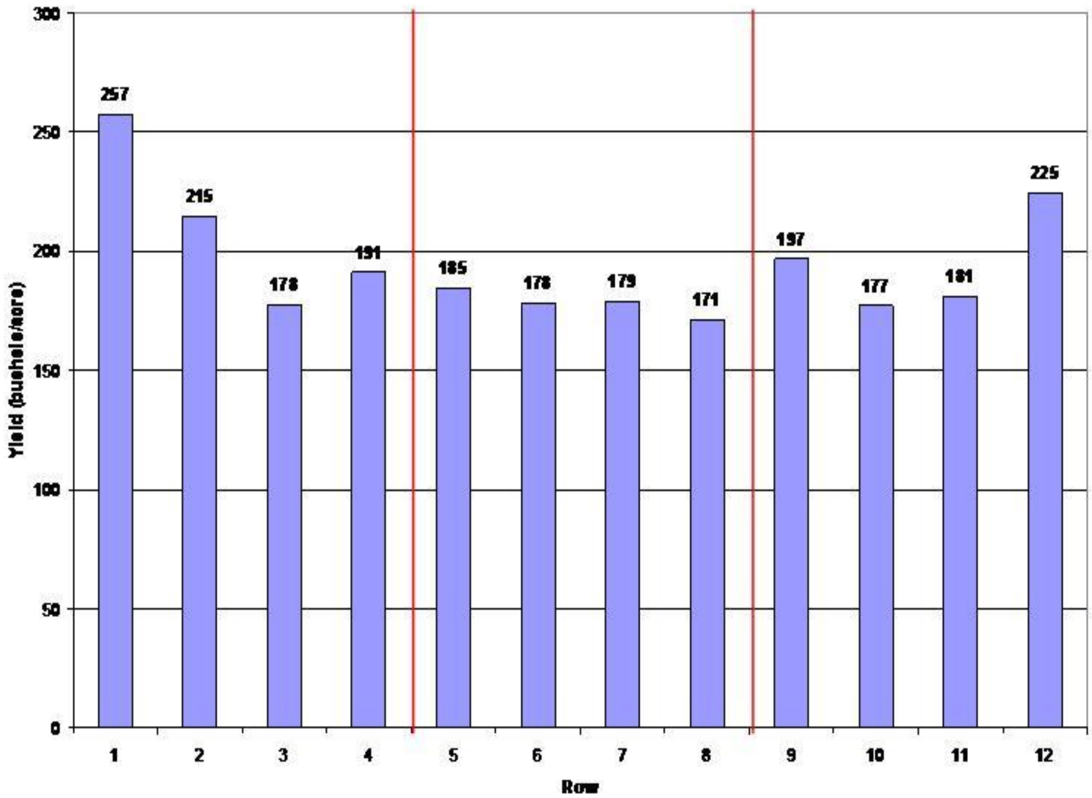
It also serves to illustrate that site specific management is not just a cell by cell or block by block issue, but it can also be done effectively on a more linear or row by row basis.

7.4 Quantifying the benefits – yield analysis

In grain maize crops, Clay has started to do yield analysis on individual crop rows. This enables him to evaluate the impact of factors such as CTF wheelings on yield.

. Using row by row analysis it is possible to measure the relative yield advantage that strip intercropping is giving to the outside rows in the planter width and also the yield detriment to the rows immediately bordering the controlled traffic wheelings. This has turned out to be surprisingly low given that the 800mm wide combine wheels actually run on a total of 4 out of 12 rows in any given bed.

The following chart is an example of the type of information gathered by Robert Recker of Cedar Valley Innovations as part of a research project funded by Practical Farmers of Iowa. The red lines are traffic lanes and data was collected across 12, ½ mile long rows. Yields are shown in bushels per acre and the extra yield benefit to the outside rows can clearly be seen.



7.5 Future developments

The next development is to attempt to find the most appropriate direction in which to plant the crops across a range of topography within a field. Site specific management on a row by row basis is also being looked at in terms of nutrition, plant population and variety choice to ensure that yield potential is not being compromised by having a blanket approach.

Whilst intercropping may not be an option directly relevant to the UK situation it does draw out some important issues that we have when it comes to accurately analyzing trial data. By removing the 'background noise' element it is possible to more readily identify the important interactions that are happening within a trial between the variables which are being studied. It may be that controlled traffic should be a criteria for variety, fertiliser and agrochemical trial work in the future to help improve the accuracy of the results. Planting direction may also be a way of optimizing light interception and yield.

8. BIOCHAR

8.1 What is it ?

Biochar or agrichar as it is sometimes called is simply a fine ground charcoal produced from organic matter such as crop residues, green wastes and manures.

8.2 Why is it significant ?

Biochar has been described as a 'double dip' for agriculture. Applications to soil have been found to give significant yield increases and reductions in input requirements. Biochar amended soils have also shown 50-80% reductions in nitrous oxide emissions, reduced run-off of phosphorous into surface waters and reduced leaching of nitrogen into ground waters. Soil structure and water holding capacity are also improved.

At the same time carbon is permanently sequestered in a very stable form long term within the soil. This means all soils are now a potential sink for atmospheric carbon. As governments look for methods to capture and store carbon before it is released to the atmosphere, agriculture can potentially go one step further and actually draw down, convert and store atmospheric carbon dioxide in a non reversible and stable form.

8.3 Global warming – fact or fiction?

The science behind climate change and global warming hinges on the fact that that we have reached unsustainable levels of atmospheric CO_2 concentrations. As a consequence emissions to the atmosphere of CO_2 and other greenhouse gases must be reduced dramatically. It is estimated that we would have to remove 230 billion tonnes of carbon from the atmosphere to reduce CO_2 levels from 383ppm to 350 ppm. This puts agriculture in the unique position of possessing all the links in the chain to remove and store atmospheric CO_2 for the long term.

Whether you subscribe to these theories or not, we have bought into carbon on a political and corporate level. The UK is committed to reducing carbon emissions by 80% by 2050. In the short term the Committee for Climate Change, that was set up to advise the government on interim targets, has recommended cuts of at least 34% by 2020.

8.4 Relevance to UK agriculture

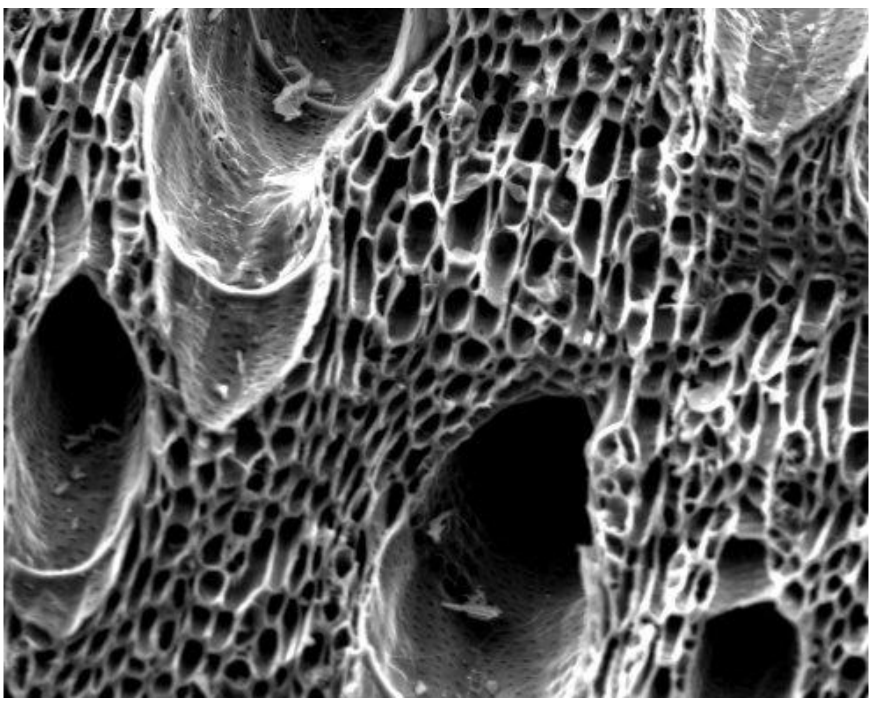
Multiple retailers aim to be carbon neutral in the near future. This means their produce will soon come under scrutiny. Calls are coming for carbon labelling of food products. Whether we are growing food or feed we are all part of the chain and will be made accountable for our GHG profiles at some point in the future. This may be as a low carbon premium in the same way we are paid for high protein in wheat or as a tax for the worst performers. Either way this will produce opportunities and issues to be dealt with.

8.5 Terra preta soils - the evidence

Ancient Amazonians are thought to have utilised the pyrolysis process to amend vast areas of soil used for agriculture in the Amazon basin. Quite how they achieved this thousands of years ago is the subject of much debate, but is likely to have been a form of 'slash and char'. This technique uses low-intensity smouldering fires covered with soil and straw. The so called terra preta ('dark earth') soils are incredibly fertile compared to the naturally occurring surrounding soils. The high fertility and carbon content of these soils has been retained to the present day. They are also thought to be self perpetuating. Using carbon dating it is possible to determine the age of the carbon and when this was done. It also provides valuable proof as to how long lasting and inert biochar is. Biochar is very difficult to oxidise biologically or chemically which is the reason it resides for such a long period in the soil.

8.6 Biochar as a soil amendment – how does it work?

One gramme of biochar has a surface area of approximately fifty square metres due to the immense porosity of the material. This in turn creates an ability to hold water and soil nutrients. Applying biochar to soils will increase the Cation Exchange Capacity (CEC) of that soil which is one of the primary reasons that it is such a good soil amendment. CEC is usually dependant on the clay component of a soil. Sandy and thinner soils therefore have less nutrient holding capacity because of this and applications of biochar has been found to significantly improve the yield potential of some of the world's poorest soils.



Photograph showing the pores and air spaces within biochar that create water and nutrient holding capabilitities.

This structure and adsorbtive capabilities will vary depending on parent material.

Source; Best Energies

Additionally biochar has been found to stimulate the growth of mycorrhizal fungi in soil. Plant roots interact with the fungi to access available nutrients and significant increases to plant growth occur as a result. This concept is relatively well known in Japan where charcoal has been used in forestry in the 1980s and then on crops and grassland in the 1990's.

8.7 How is Biochar produced

Biochar can be produced from any plant matter including wastes and by-products. Paper mill waste, green waste, animal manures and crop residues are all usable.

The energy within this material could be released by combustion, but in this process the carbon content of the organic matter combines with atmospheric oxygen to form carbon dioxide. In an open fire for example this is then lost to the atmosphere. This is in contrast to biochar production where much less carbon is released.

Biochar is produced by a process called pyrolysis. This involves heating the biomass to around 550 degrees Celsius in the absence of oxygen. An external heat source is required to start the process but eventually enough energy will be produced to fuel the process. Energy can therefore be released from the material without actually burning it. In turn this energy fraction is utilised and other by-products of the process in the form of bio-oils and syngas can be collected and used. Hydrogen rich syngas can be produced and used for ammonia synthesis and fuel production. These have the advantage over the initial biomass in that they are more concentrated and more readily stored and transported.

The charcoal that is produced at the end of the process may contain up to 65% of the initial biomass carbon. This is largely resistant to decomposition when added to the soil. Even though charcoal still contains a proportion of energy as it is itself a fuel source, once added to the soil it will never be burnt and the process reversed. This cannot be said for forestry as a sequestration technique, where one match and a forest fire can reverse the whole process.

8.8 Raw materials

Fossil fuels could be used to produce biochar but the argument is that these materials are historically sequestered sources of carbon. This process happened millions of years ago using ancient sunlight. Even if pyrolised instead of combusted, and a 50% retention of their carbon content is achieved, this still results in a 50% net release to the atmosphere. By contrast using fresh biomass will result in 100% of the contained carbon coming from the atmosphere today when the material is growing and return only 50% in conversion to biochar. This gives a net permanent sequestration of 50%.

Biofuels have come under increasing scrutiny recently as their environmental profiles have been investigated. On the one hand they draw down atmospheric CO_2 during the growing phase of the crop. This is then released back to the atmosphere during the combustion of the fuel and the decomposition of the residue. To this point they are therefore carbon neutral with equal amounts of carbon used and produced. However, when the crop inputs of seed, chemical, fertiliser fuel and associated processing and transport are included the net carbon and GHG balance looks increasingly marginal. The environmentally friendly biomass crop is not much better than fossil fuels in terms of net carbon release.

In 2008 the USA witnessed an increasing backlash against the state funded ethanol programme. ‘Evil ethanol’ was blamed for escalating food prices by taking food acres out of production to produce fuel. With food stocks lower this in turn drove up prices and consumer sentiment changed to dislike of the green fuel programme. Unfortunately it seems the consumer can no longer ‘afford to be fussy’.

Producing biochar from crop by-products such as straw and corn stover would be a way of redressing the carbon balance and retaining a greater proportion of the carbon captured in the growing crop. When chopped and left on the field around 90% of the carbon within crop residues is returned to the atmosphere as CO_2 after decomposition. The remainder will find it’s way into the long term stable pools of soil carbon. Increased levels of cultivation are also responsible for greater rates of oxidisation of soil organic matter. Converting residues to biochar would ensure that a much greater proportion is retained as long term and stable soil carbon.

Again the associated GHG emissions associated with collecting, processing and replacing nutrient offtake have to be calculated to decide whether it is a feasible proposition. The fledgling biochar industry that exists globally is gathering pace, but until recently the concept has been in the hands of scientists. The next step towards monetising the concept is proving challenging.

8.9 Production processes

Potential biochar producers have logistical considerations. A large fixed plant offers potential for economies of scale but needs a steady flow of feedstock material. Green waste and food waste are year round available materials that also generate gate fees. To this can be added woodchip and crop residues if the location allows. Any distance from an area of agricultural production and transport costs become prohibitive. Smaller, mobile processing plants have been proposed to move around production areas to make use of materials and keep down transport costs.

The parent material used along with the heat and time of the process will determine the composition of the end product. High lignin materials will generally produce more carbon. A high quality biochar will have as high a level of carbon retained as possible without any impurities. Other main constituents apart from the fixed carbon are volatile matter and ash. The nature of the volatiles is of significance as they may have the potential to affect crop germination if applied to soils. As yet here are no internationally recognised standards for biochar as would be the case for fertilisers.

8.10 What price carbon?

Extensive field scale research has been carried out internationally to try and gauge the benefits of biochar. To get the agronomic benefits application rates are quite high. 5-20 tonnes per acre have been used with no adverse effects and subsequent applications have also been applied.

The cost to produce biochar is around £100-200 per tonne using green waste converted by pyrolysis according to Best Energies in Australia. To apply these rates of application at these prices is not currently economically viable. Currently production plants are relatively small scale for demonstration purposes. They can, however, produce enough for experimental field work. The largest field trial is at the Department of Primary industries at Wollongbar, Australia. Lukas Van Zwieten and his team have a range of trials to try and quantify the agronomic benefits and also the impact on reducing nitrous oxide emissions.

8.11 Other uses

Biochar can also be used to decontaminate areas where pollution has occurred. Former mine sites that have high levels of contamination, many of which are toxic, can have issues with surface and drainage water pollution. The charcoal has been used to soak up these contaminants. Only cations are bound which means that elements such as arsenic are not collected.

Charcoal is also used as a modified selective catalytic reactor (SCR) to clean up exhaust from power generation. In the process of removing CO_2, nitrous oxide and sulphur oxide the charcoal is enriched with nitrogen and sulphur creating an enhanced fertiliser as well as soil amendment.

The biochar concept has been adapted by Virginia based poultry farmer Joss Frye in conjunction with Illinois base gasification expert Mike McGolden of Coaltec. In this case the poultry litter is put through a gasifier to produce combustable gas with which to heat the poultry units. This replaces propane with the advantage that it keeps the humidity low in the buildings. 10 litres of propane puts 8 litres of water into the air. This water vapour mixes with NH_3 to produce ammonia. By not using the propane the relative humidity levels, ammonia levels and bird stress levels are reduced. As a secondary benefit a low grade biochar is produced that is sold to arable farmers for $600 per tonne.

8.12 Biochar conclusions

Biochar has been proven to be a good soil enhancer with potential to reduce inputs, especially nitrogen. Not only are nitrates retained for plant use, but losses are reduced through less leaching. Nitrous oxide emissions are also lower which is of particular relevance given that they are one of the more potent greenhouse gases.

Although it is currently costly to produce, biochar is a very attractive as a carbon capture and storage technique. It's future will depend on the price of tradeable carbon and government commitments to climate change targets.

Agriculture is well placed to benefit from biochar as it can provide the parent material, use the product for soil enhancement and act as a large scale sink for atmospheric carbon. Whilst there is energy in the material that goes into the ground, it has been calculated that at today's energy and fertiliser prices, this is more than offset by the benefits it incurs as a soil improver.

9. Summary

Before commencing my study, my preconceptions were that it should be possible to find ways to tweak what we are currently doing to make some subtle improvements. What has now become apparent is that there are a multitude of major things that we could be doing to make our use of inputs more efficient. At the same time we could also be delivering substantial environmental savings in the form of reduced greenhouse gas emissions and carbon sequestration.

I feel that GM crops are the one technology with the most to offer farmers, consumers and the environment. The trade off is between a technology potentially unproven in the long term and one that can cut out many of the undesirable aspects of farming, whilst in the process delivering direct benefits to the consumer. Significant reductions in agrochemicals, fertiliser, cultivations, fuel use and capital expenditure are all possible. The British public would see less spraying taking place with a large reduction in the amount of pesticide and fertiliser entering the environment. Given the stringent EU limits for drinking water, any reduction in chemical or fertiliser applications would also reduce costs associated with complying with this regulation. GM also delivers environmental savings by way of reduced GHG emissions from the associated manufacture, distribution and use of the products displaced.

In the US, farming is getting easier due to GM. They are spending less, cultivating, fertilising and spraying less, producing more and margins are improving. In the UK, we are faced with more fertilising and spraying, a diminishing pesticide armoury and lower efficacy. The result is that we will have to move to more cultural control measures to control weeds, pests and diseases. Stale seedbeds, later drilling and more spring break crops will be necessary. They may work to an extent, but this comes at a price and margins will suffer and management intensity will increase. The gap is widening in terms of how competitive we are in a global market. Our unit costs of production are much too high and rising. Additionally our ability to compete for high priced inputs is also lower than our competitors. We are getting left behind at an alarming rate.

Soil health is a huge priority and there is increasing legislative pressure on farmers to look after their soils. Soil management plans for Single Farm payment cross compliance and Enviromental Stewardship are examples of this. Optimum soil structure is fundamental to producing good crops. If this is achieved it is possible to generate financial and environmental savings. If we look after our soils, our soils will look after us.

Good crop rooting is essential and will enable recovery of a greater proportion of applied nutrients. If more nutrients are utilised, less is available to leach out of the soil profile into groundwaters. CTF and strip tillage are ways of improving soil structure, soil health and crop yield. Cultivation requirement should also be less, reducing both costs and GHG emissions.

According to CTF Europe, studies have shown that the system can reduce fuel usage by 35%, reduce energy costs by up to 70%, give 15% better recovery of nitrogen fertiliser, increase infiltration of water reducing soil erosion by 40 % and improve soil aeration leading to reduced nitrous oxide and carbon dioxide emissions.

In the UK strip tillage could be suitable for crops grown on wide rows such as oilseed rape, field beans, sugar beet and maize. It could also provide an alternative to the current DEFRA proposal for over winter cover crops preceding all spring sown crops. Used in conjunction with CTF, it could ease the transition from conventional tillage to a minimum or no-till system.

The concept of precision banding of fertiliser is already starting to catch on and is possibly the easiest system to adopt or introduce on farm. The same technology can also be used for band spraying of chemicals. A significant reduction in the amounts of materials used can be achieved in this way. By farming accurately it is possible to direct inputs exactly where they are required. Blanket applications were the easiest way before the onset of GPS based technologies. Now it is possible to do site specific cultivations and applications on a block by block or linear basis.

Precision farming is moving forward rapidly. The challenge lies in understanding enough to maximise the potential. High accuracy GPS in the form of RTK is the glue that holds many of the concepts together and this will prove to be a tremendous enabling technology moving forward. The cost of this can be minimised by potential users co-operating or subscribing to existing networks.

Nitrogen fertilisers account for 80% of farm GHG emissions through use and associated manufacture. Site specific applications in the form of in-row placement and VR applications can not only save cost but have a massive impact on our environmental profiles. The vast majority of UK farms now fall within a Nitrate Vulnerable Zone (NVZ). In row fertiliser placements allows a lower overall application rate to be used, whilst delivering a higher relative dose. This could prove very useful when trying to remain compliant with N max limits.

Cutting back on input use on farm will reduce total GHG emissions. However this is not conducive to maximising margins or environmental efficiency. What farmers and legislators need to focus on is reducing emissions per unit of output. This is a very important consideration and something which has to be considered when shaping policy in the future.

As our government continues to make pledges to cut Greenhouse Gas emissions there will come a point in the near future when agriculture becomes actively involved. This may take the form of a premium for low carbon products or a tax for the worst emitters. Whatever the case we need to have some answers ready. The opportunities in the carbon market are in change. The current industry standard is the default position. This may be our current cultivation policy for example. A change to CTF or strip tillage would give quantifiable benefits over and above the default. This potentially has a value by reducing the carbon content of the associated produce or by acting as a carbon offset on the voluntary carbon markets.

Biochar is something to watch in the future. The concept is sound, but the economics are currently prohibitive. Given political commitment to cut carbon emissions in the medium term this could be at the forefront of carbon capture and storage schemes. If this does become a reality then UK agriculture is very well placed to capitalise as a potential producer of the raw materials, user of the product as a soil amendment and as a carbon sink provider. Biochar could also alter the profile of biofuel crops from carbon positive to carbon neutral. Up to now it has been felt that biofuels only deliver a marginal environmental benefit over fossil fuels.

10. Recommendations

Much of the UK Precision farming industry is in the hands of manufactures of hardware or inputs. I would like to see more farmer groups undertaking knowledge share and doing on farm trials to evaluate systems. Australian farmer group SPAA (Southern Precision Agriculture Association) have a tremendous following of farmers to the extent that the manufacturers are now involved after initially being very reticent.

Equally leading UK research groups and organisations that have funding appear very reticent to step into the realm of PA. Consequently there is very little impartial work done to evaluate new systems such as crop sensing and variable rate technology.

Universities and colleges in the USA have some fantastic training courses for farmers to attend regarding the gathering, interpretation and analysis of spatial information and general understanding of PA. A better understanding of the fundamentals would allow users to make more informed decisions when it comes to selecting and purchasing expensive technology and systems.

RTK is becoming more affordable. Co-operation and subscription to existing networks are both alternatives to outright purchase.

CTF Europe is one very effective farmer group that we do have, that is encouraging the sharing and dissemination of ideas and experiences. For anyone considering CTF, this would be a great starting point as they have a useful focus on north European conditions.

We need more creative agronomy to think our way round many of the challenges with which we are faced. Blanket spraying of every acre is not sustainable. Site specific applications within fields are. The driver for change has to come from the farmer and agronomists should be asked to help deliver it. Variable rate and site specific chemical and fertiliser recommendations would enable growers to make the transition, whilst generating a new income stream for the advisors.

GM without doubt offers some very robust solutions to a lot of problems and is the one technology that can deliver both cost and environmental savings in a big way. What we have to consider is whether we are doing more damage to the environment and ourselves without GM than with it. It used to be hard to argue a case for GM as all the benefits were related to the farmer. Now GM can reduce the amount of pesticides and nitrates entering the environment, reduce the amount of spraying, reduce GHG emissions, and still produce cheap food with built in health benefits. I believe that this is the future of UK arable farming.

APPENDIX

1. Impact of Conservation Practises on Soil Erosion in Northwest Iowa by the Department of Agriculture and Biosystems Engineering, Iowa State University.

Results for 5 different watersheds to compare different cultivation practises on soil erosion:

Region 1 (Elk Creek- Little Sioux River Watershed). 180 acres, mean slope 2.6%

	No-till	*Strip-till*	*Disk-Till*	*Chisel-till*	*Conventional*
Runoff(inch/year)	*2.24*	*2.49*	*2.69*	*2.86*	*3.16*
Sediment yield(tons/acre/year)	*0.43*	*0.58*	*1.48*	*2.07*	*4.20*
P on sediment (lbs/acre/year)	*0.72*	*0.98*	*2.48*	*3.48*	*7.05*

Region 2 (Upper Buttrick Creek Watershed). Mean slope 0.4%.

	No-till	*Strip-till*	*Disk-Till*	*Chisel-till*	*Conventional*
Runoff(inch/year)	*3.25*	*3.63*	*3.62*	*4.00*	*4.22*
Sediment yield(tons/acre/year)	*0.16*	*0.18*	*0.30*	*0.45*	*0.61*
P on sediment (lbs/acre/year)	*0.33*	*0.37*	*0.62*	*0.92*	*1.27*

Region 3 (Buffalo Creek-Silver Creek Watershed) 280 acres. Mean slope 1.7%.

	No-till	*Strip-till*	*Disk-Till*	*Chisel-till*	*Conventional*
Runoff(inch/year)	*2.16*	*2.74*	*2.77*	*2.80*	*3.06*
Sediment yield(tons/acre/year)	*0.19*	*0.31*	*0.61*	*1.00*	*2.39*
P on sediment (lbs/acre/year)	*0.26*	*0.42*	*0.81*	*1.33*	*3.15*

Region 4 (Rock Creek – South Skunk River Watershed). 210 acres. Mean slope 2.6%.

	No-till	*Strip-till*	*Disk-Till*	*Chisel-till*	*Conventional*
Runoff(inch/year)	*4.18*	*4.15*	*4.02*	*4.08*	*4.15*
Sediment yield(tons/acre/year)	*0.42*	*0.65*	*1.46*	*2.07*	*4.02*
P on sediment (lbs/acre/year)	*0.47*	*0.74*	*1.68*	*2.36*	*4.59*

Region 5 (West High Creek Watershed). 108 acres. Mean slope 2.9%

	No-till	*Strip-till*	*Disk-Till*	*Chisel-till*	*Conventional*
Runoff(inch/year)	*4.64*	*4.58*	*4.48*	*4.60*	*4.79*
Sediment yield(tons/acre/year)	*1.14*	*1.73*	*5.83*	*7.45*	*12.15*
P on sediment (lbs/acre/year)	*1.31*	*1.99*	*6.66*	*8.51*	*13.88*

In all 5 regions, soil erosion was simulated for 4 reduced tillage systems (no-till, strip-till, disk-till and chisel till) and conventional tillage. No-till had no soil or crop residue disturbance except for that occurring during planting. Strip tillage prepared narrow rows for planting. Disk till included autumn and spring field cultivating. Chisel till included autumn chisel operation and pre planting cultivation in the spring. Conventional tillage included subsoiling after harvest and cultivating and discing in the spring.
In this study a Water Erosion Prediction Project (WEPP) model was used to simulate soil erosion for a 30 year period to obtain mean annual surface run-off and sediment yield.

Regions 1,2 and 3 all show improvements by reducing tillage levels down to zero. Here strip till is an improvement to more conventional tillage. However regions 4 and 5 show high levels of run-off and erosion through no tillage. This could be due to compaction causing low levels of permeability to water. In both these cases it is important to point out that strip-till gives an improvement to no till, to similar levels to a conventional tillage approach.

This study gives an indication to why strip-till is also referred to as conservation tillage.

CONTACTS

CTF Europe	Controlled traffic farming	www.controlledtrafficfarming.com
VNTFA	Victoria No-till Farmers Association	www.vicnotill.com.au
WANTFA	Western Australia No-till Farmers Association	www.wantfa.com.au
SANTFA	South Australia No-till Farmers Association	www.santfa.com.au

Remlinger Manufacturing	Strip-till equipment	www.remlingermfg.com
Orthman Manufacturing	Strip-till equipment	www.orthman.com
Environmental tillage systems	Strip-till equipment	www.soilwarrior.com
John Deere	Strip-till equipment	www.deere.com
Redball Products	Strip-till equipment	www.redballproducts.com
Yetter Farm Equipment	Strip-till equipment	www.yetterco.com
Bigham Brothers	Strip-till equipment	www.striptillage.com
Kinze Manufacturing	Row crop equipment	www.kinze.com
Hagie Manufacturing	Sprayers	www.hagie.com
Agleader Technology	PA equipment	www.agleader.com

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Steve Larocque, Beyond Agronomy	www.beyondagronomy.com
Farmers Edge Precision Consulting	www.farmersedge.ca
Reduced tillage linkages	www.reducedtillage.ca
RTK of Iowa	www.rtkofiowa.com
Australian Centre for Precision Farming (ACPF)	www.usyd.edu.au/agric/acpa
SARDI**,** South Australian Research and Development Institute	www.sardi.sa.gov.au
SPAA, Southern Precision Agriculture Association	www.spaa.com.au

Jim Robbins, Canada
Craig Shaw, Canada
Robert Stewart, Canada
Richard Heath,Australia
James Hassall, Australia
David Brownhill, Australia
Jamie Grant, Australia
Robert Ruwoldt, Australia
Clay Mitchell, USA
Dennis Smith, USA
Josh Frye USA

N/C Quest	Exhaust Gas Systems	www.bioagtive.com
Monsanto	Biotechnology	www.monsanto.com
International Biochar Initiative (IBI)		www.biochar-international.org
Department of Primary Industries (DPI),	Wollongbar, Australia	
Best Energies	Pyrolysis	www.bestenergies.com
Rothamstead Research Institute		www.rothamsted.ac.uk
Mike Mckinnon, Coaltec, Illinois	Gasification	www.coaltecenergy.com

(BBC - Science & Nature documentary - Horizon - The Secret of El Dorado)

WHERE NOW ?

Having completed my Nuffield study, the next step is to start making some changes.

The first thing we have done is to move from an Omnistar XP based GPS system to an RTK network. This will run autosteer and sprayer boom section control initially. Yield mapping is currently done using basic GPS and this along with variable rate applications and soil sampling are the next areas to be set up for RTK.

The next area that will hopefully be in place for the 2010 season is the precision banding of fertilizer within the crop row during planting. Initially this will be with liquid fertilizer for oilseed rape crops.

Controlled traffic farming and reduced cultivations will be most difficult to implement effectively on heavy land with high grassweed pressure. Experimentation is certainly the word moving forward.

As was pointed out to me on my travels "The definition of stupidity is doing the same thing over and over again and expecting different results" – Albert Einstein.