A Nuffield Farming Scholarships Trust

report

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The Alan and Anne Beckett Award

Soil Fertility and Fertility Use Efficiency

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NUFFIELD UK

Contents

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Executive Summary

In UK arable farming we are currently facing many challenges from increasing costs to herbicide resistance and plateauing yields. Government research is showing that through soil erosion we are losing 0.1-0.3t/ha of top soil annually and it is the most fertile soil which is lost first. This comes at a time when climate change is being widely accepted and we are tasked with the challenge of producing more while impacting less. We have noticed differences in soil structure and fertility on our home farm, which previously had a livestock enterprise, compared with other land that we farm which has no history of livestock. These range from improved workability through to less weed resistance problems and have led us to questioning why the differences are so great. When this question was raised it became very apparent how little we actually knew about what was happening below ground level and led to my application for a Nuffield study tour scholarship.

Very often I believe that we, as farmers, have forgotten that the soil is alive and made up of billions of living soil organisms. When we begin to manage it as a living organism we suddenly treat it with much more respect than we do when thinking about it as a medium. Like other living organisms soils breathe and require feeding. To provide adequate nutrition they require a living root system growing to excrete sugars through the root system to the soil biota. If the soils do not have enough nutrition then the soil biology either becomes dormant or dies, and the same happens if there is not enough oxygen or too much water in the soil profile.

We now begin to understand that the soil is very complex and it is with sadness that I don't feel that the current Fertiliser Advisory System (FACTS) goes into enough detail to maximise efficiency and productivity, instead focusing on the major inputs of N, P, K and pH which, when applied in the wrong form, can be less than 10% efficient. The uptake of the Albrecht system of soil analysis is being slowly adopted around the world and this test gives a much more detailed analysis of what is happening within the soil and a greater understanding of which fertilisers will work on that soil type. A dairy farmer from South Australia has adopted this technique wholeheartedly with extremely impressive results which has enabled him to survive and thrive during their seven year drought.

Farmers need to understand the importance of organic matter on soil fertility. It is critical for the functioning of soil on all levels: physical, chemical and biological. Organic matter stores water, provides nitrogen and resists compaction. Between 1980 and 1995 18% of organic matter in arable soils was lost. Organic matter is carbon so when losing organic matter we are losing carbon. When deciding to sell organic matter it needs to be a conscious decision that it is not just the chemical components of P and K that are leaving the field.

Cover crops have a very important role to play in improving the condition of our soils because through their above ground and root growth they can reduce leaching and increase organic matter levels. More importantly in agriculture we only have one free energy source, the sun. Via photosynthesis we convert this 'free energy' into organic matter and help store carbon within the soil. The more energy we intercept the more likely we are to create a sustainable farming system.

Around the world I also saw many farmers who were direct drilling and in Argentina I met one of the pioneers of no-till in South America. He is farming on a soil with 35% clay and his crops were immaculately produced with no visible compaction. He is also receiving over 1000mm of rainfall annually. I see a gradual growth in the role of conservation agriculture in the UK.

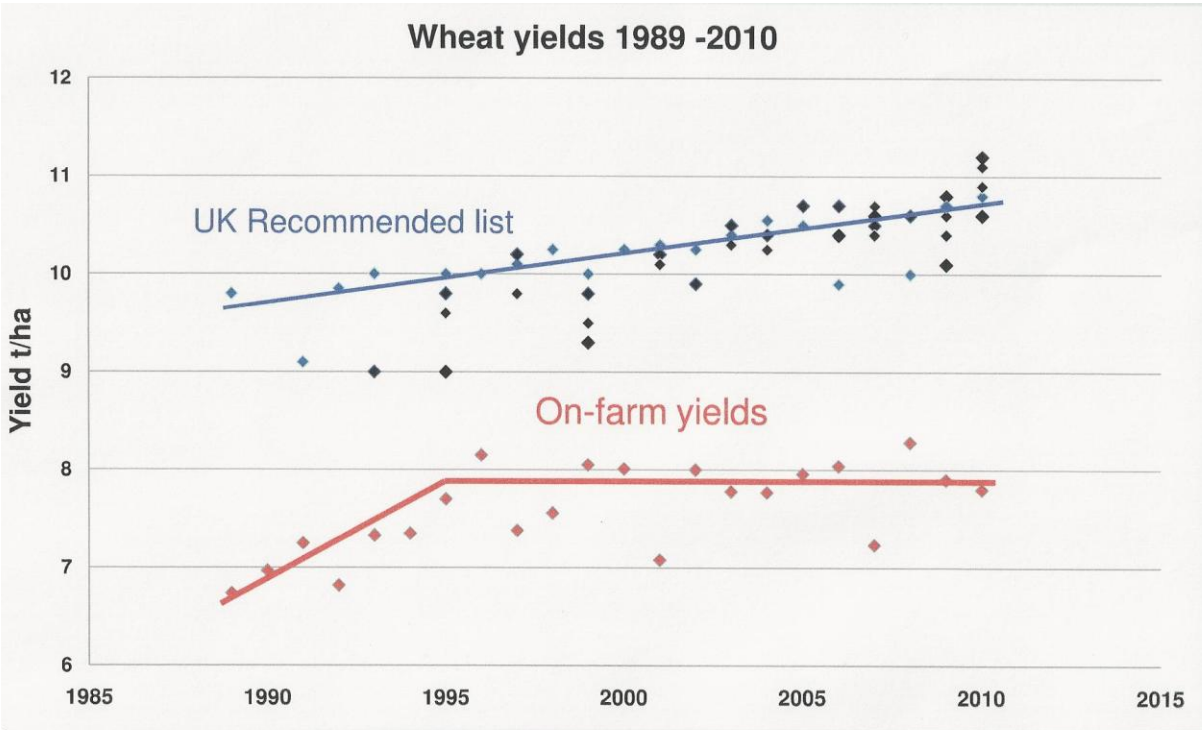
1. Background

I am a 4th generation farmer's son from Essex. We have a small family farm of 160 acres which has been owned by the family since the early 1950s and was originally a traditional mixed farm with sheep, cows, pigs and a small amount of arable. Being bought up as one of three boys it was quite clear that the home farm was not going to be able to support all of us if we all decided we wanted to follow a career in farming so we branched out into contract farming, originally with dairy farming in 1997 and then arable farming in 2002. Since then we have been lucky enough to continue to expand this side of the business and we are now contract farming 3200 acres of arable with further work carried out across another 650 acres, plus we also have approximately 500 acres of grassland and environmental stewardship which is managed alongside this. The home farm no longer has a livestock enterprise, which is indicative of a change on many farms in East Anglia over the past 30 years, although it does have a thriving equestrian unit, with the remainder of the land being used for arable production.

I was educated at Colchester Royal Grammar School where I successfully gained my GCSEs and A levels before heading off to Wye College in Kent to gain a degree in Agricultural Business Management. I was always sure that I wanted to forge a career in agriculture and, after working away from home during all my University holiday periods, I then spent six months gaining further experience on the Southern Canterbury Plains in New Zealand before returning to the family farm in April 2004. I was lucky that with the growth of the business we were in a position where we were about to employ an Arable Manager so there was a position for me to step into. Since returning to the farm I have gained my BASIS and FACTS qualifications and now carry out the agronomy across the whole area. We have also embraced all areas of Precision Farming over the past 6 years from precision application of phosphate, potash and nitrogen fertiliser through to yield mapping and machine control.

2. Introduction

We have seen variable costs for a crop of wheat double from £250/ha in 2005 to £500/ha in 2010 and we are currently experiencing fixed cost inflation (machinery, fuel, labour etc) running at around 12.5% per annum. In 2006 our fixed costs were approximately £200/ha and in 2011 this figure is around £320/ha. Thankfully these cost increases have come during a period where commodity crop prices have been generally firm, although with huge volatility, which has meant that crop margins could be maintained. I say thankfully because speaking to many arable farmers it seems to be a general consensus that wheat yields have definitely plateaued over the past 15-20 year period with the holy grail of 10t/ha wheat average something which is now more difficult to achieve than it was during the 1990s, despite advances in yield potential, through breeding, of 1% per year.

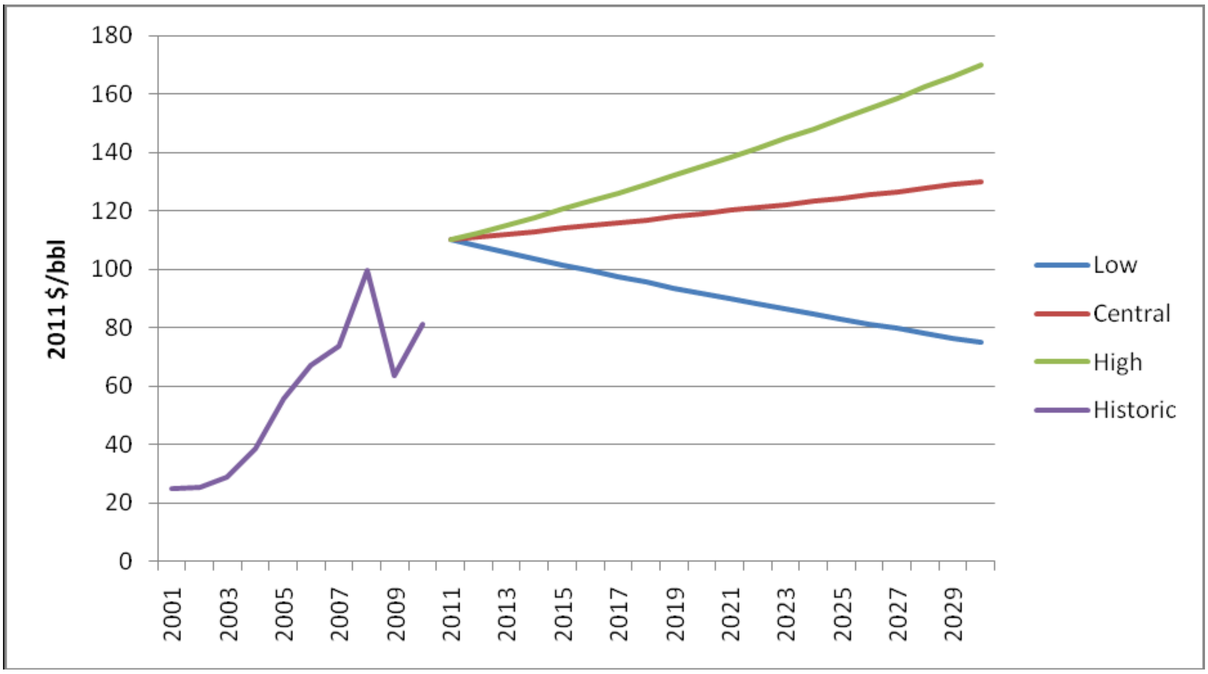


Source: Broom's Barn, Rothamsted Research

This all comes at a time when weather events seem to become less predictable and more extreme and we are being tasked with the job of 'sustainable intensification' which I believe has to mean producing more from less or even the same from less or, more scientifically, more output per unit of input.

The majority of the cost increase above can be traced back to the role of fossil fuels within the agricultural industry from fuel through to fertilisers, agrochemicals and machinery manufacturing costs. The graph on the next page shows the historic oil price over the past decade and future projections through to 2030. If we took a trend line for the past decade then it would be very close to, if not above, the highest projections on the graph.

See graph on next page.



Department for Energy & Climate Change Oil Price Predictions

All the above led me to ask more questions about what we needed to do to achieve better cost control and the conclusion was, quite simply, that we need to make better use of our inputs so we can increase our efficiency levels. The efficiency of nitrogen used nationally for 2011 is predicted to be just 45%, which is completely unacceptable, and even in a good year we only achieve figures for efficiency of up to 60%. Unless we start questioning why we have these poor efficiencies and what is happening to the remainder then we will not be able to achieve better.

On our farm one thing we had noticed was that where we had a history of livestock our soil fertility was much higher and that we did not require the same levels of nitrogen, a lesson that I learnt the hard way with several fields of flat wheat after believing that I knew better than my father. On this same farm we were also noticing that we did not require the same level of cultivation to achieve a seedbed as we did on some of the clay soils that did not have a history of organic matter. This again was giving many clues as to where the answers lie in the future of soil fertility.

The final piece in the jigsaw which made me think about applying for a Nuffield Scholarship was reading a book called 'Hands-on Agronomy' by Neil Kinsey and Charles Walters which introduced the 'Albrecht' method of soil fertility and crop nutrition. This completely contradicts the standard approach to soil fertility used in the UK and recommended by the fertiliser manual, RB209.

I had got to the point where I needed some answers and none of the questions above had been discussed in any part of my formal agricultural training.

Finally I filled in the application form and went off on a journey of discovery, meeting many fantastic people, having a great time, but most importantly opening my eyes and mind to different production systems.

I purposely set out to see best practice in different agricultural systems: ranging from organic dairy production in Australia, based on the Albrecht soil fertility programme, through to large scale production of Biotech crops in Argentina. I searched for the most highly respected Sustainable or Eco Agricultural advisors in the UK, Australia and America through to spending time with one of the most technologically advanced Agribusinesses, Monsanto, in Argentina.

Below I will outline my findings and try to give some direction to what I believe is a general step in the right direction.

2. What is soil?

Before we progress any further I believe it is important for us all to remember exactly what soil is and the ideal make-up of that soil. This thought process helps the whole farming system progress and stimulates the question: 'what are we managing for?' particularly in relation to cultivation strategies.

1. **Soil is a living organism**
   Like other living organisms soils breathe and require adequate nutrition and water. Livestock require appropriate management to maximise growth and herd health; the soil is no different.

2. **Soil nutrition**
   Soils have a basic nutritional requirement for optimum management and sustainability. To maintain a healthy soil regardless of what is growing on it the soil biology requires a nutrition source, which is usually provided by root exudates. Without these exudates the soil biology either dies or goes into dormancy.

3. **Soil life**
   The life of the soil encompasses all living organisms including insects, worms, bacteria and fungi. Without these organisms the soil would be dead and unproductive. Soils organisms perform the following important functions:

   - Improve nutrient availability
   - Improve soil structure, moisture availability and drainage
   - Protects plants from pathogens

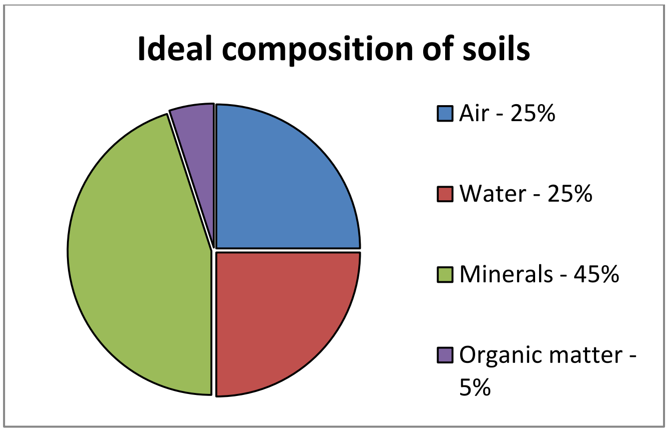
   As an example, earthworm vermicast contains 7 times more phosphorous, 10 times more potassium, and 5 times more nitrogen than the base soil (*Graeme Sait 2011*).

4. **Soil structure**
   Soil organisms require the right environment to flourish, from the nutritional make-up of the soil through to the physical properties of a soil. It is an absolute necessity for farmers to realise that the problems created by soil compaction go far beyond water logging and poor root structure. If a soil becomes badly compacted then the soil often turns anaerobic and therefore toxic to organisms and roots.

One of the most important tools in the armoury of a farmer is not the 500hp tractor and 6m cultivator but the £200 penetrometer.

This simple tool shows if the soil structure is in a condition which allows roots to penetrate.

The chart on the next page shows the ideal composition of soils.



The soil should be 50% physical components and 50% pore space. The ratio of water to air in the pore space varies depending upon the moisture content of the soils. In compacted soils the pie chart may get to the stage where the water takes up all of the space that should be occupied by air.

4. Current fertiliser guidance in the UK

As farmers we are required to have all fertiliser recommendations made by a FACTS qualified advisor and the basis of all advice is from the fertiliser bible, RB209. I gained my FACTS qualification in 2006 and on award of the certificate this meant that I could go out with my trusty handbook, RB209, and give advice anywhere in the country about fertiliser requirements. The question that I now ask is: did this 'qualification' really give me enough knowledge to be able to do this accurately and ensuring that best practice was going to be used at all times? Unfortunately the answer I come up with is a resounding 'no'.

This is not to knock the FACTS certification scheme because I think it is a very important discipline for anyone who has an active role within the agricultural industry and shows that the farmer is taking due diligence and a responsible approach to crop nutrition. What really worries me is that the majority of our fertiliser advice is carried out by people who possess no more qualifications than FACTS.

If nitrate leaching and phosphate pollution are proven to be an industry related problem and we want to try and significantly reduce water pollution from these sources then we need a much greater understanding of what is responsible for these problems and how we can reduce agriculture's contribution to them. I don't believe that this is something that the FACTS qualification gives any credence to and a more detailed fertiliser advisory certificate may be required. The same is true if we want to increase the efficiency of use of nitrogen.

My other major worry about current fertiliser advice in the UK is that one book, RB209, is used to fit all circumstances, from a hill farmer in Yorkshire to an East Anglian arable producer. Yes it is tailored for different crops and different grazing techniques and different soil types but it still leaves many decisions for the farmer to make himself. Every farmer will tell you he has some heavy clay soil or some light sand but an individual farmer's idea of each is very different and the definitions within RB209 of each different soil type are left open to interpretation. If you decide that your soil is shallow/sandy rather than medium/heavy then it is assumed that the percentage of available nitrogen from autumn applied slurry can vary by 20%. I believe that if the Cation Exchange Capacity (CEC) was shown on a standard soil sample and the guidelines within RB209 were based upon CEC then the system would be a lot less open to misinterpretation.

4.1 Cation Exchange Capacity

Cation-exchange capacity is defined as the degree to which a soil can absorb and exchange cations.

Cation – a positively charged ion (NH_4^+, K^+, Ca^{2+}, Fe^{2+}, etc…)

Anion – a negatively charged ion (NO_3^-, PO_4^{2-}, SO_4^{2-}, etc…)

Soil particles and organic matter have negative charges on their surfaces. Mineral cations can adsorb to the negative surface charges, or the inorganic and organic soil particles. Once adsorbed, these minerals are not easily lost when the soil is leached by water and they also provide a nutrient reserve available to plant roots.

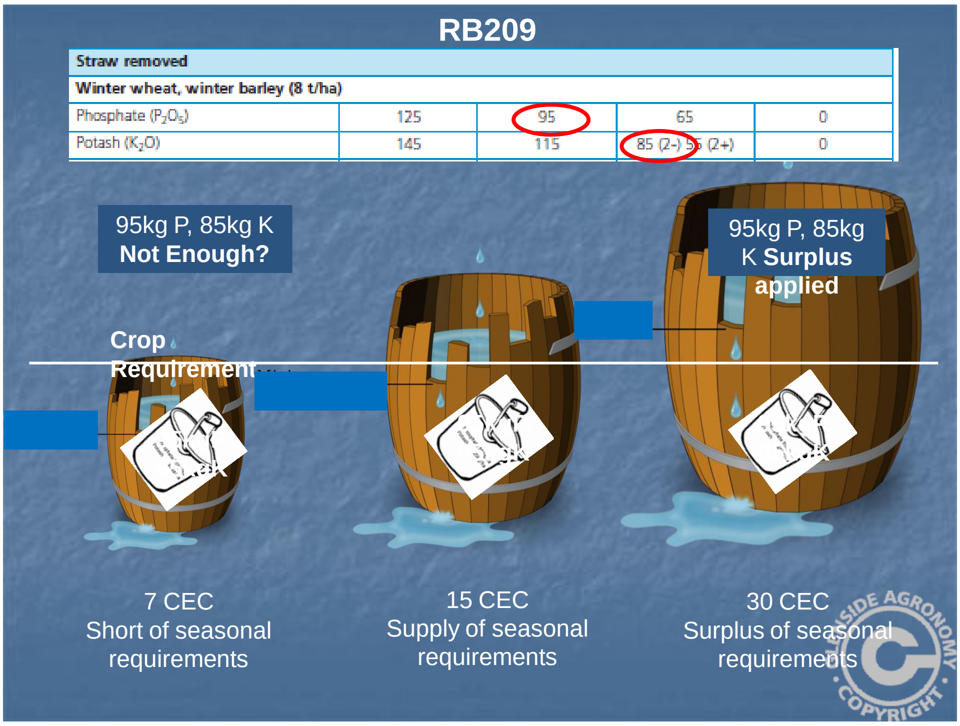
These minerals can then be replaced or exchanged by other cations (i.e. cation exchange)

I believed that I farmed some heavy land in Essex and was regularly told that it was ‘proper good old wheat ground’ and I would have categorised it as deep clay. I then sent off some soil for a detailed Albrecht analysis which was going to show the CEC, amongst other things. I was expecting a result in excess of 30 but when the result came back and the CEC was only 14.88 it made me further question what was happening with this soil. The full results of this soil analysis are shown on page 12.

Unfortunately, I believe that a very complex soil system has been oversimplified in the current teaching to try and find a “one approach fits all” solution and needs much greater research if we are to try and move the industry forward on a sustainable level. This is important from a cost control point of view and therefore profitability, plus at an environmental level.

4.2 Conflict between RB209 and CEC

The diagram below aims to show why RB209 is not correct at varying CEC levels. The three barrels below represent soils with different CECs: a light sandy soil to the left with a very low CEC, a medium bodied soil in the middle and a very heavy clay soil to the right. The barrels aim to demonstrate how Justus von Liebig's **Law of the Minimum** (stating that yield is proportional to the amount of the most limiting nutrient) applies. On the top of the diagram are the recommendations from RB209 which are the same for each soil type. The problem comes when, because the soil with the lower CEC can store less nutrients, it requires more than this recommendation applied for the crop requirement, whereas the soil with the higher CEC may not require anything applied, even though the soil indices are the same.



The slide on the previous page *(source : Glenside Agronomy)* also raises questions as to the need for and the accuracy of our variable rate phosphate (P) and potassium (K) applications. At home we have been using variable rate fertiliser for 5 years and it has reduced our fertiliser input significantly over that period, allowing us to run down areas of the fields with higher indices and improve areas with lower indices.

The trouble is that with the information above I now begin to feel that a more important measure of our soils is the CEC. Until we know what the CEC of the soil is we cannot accurately assess how much P & K is required which makes the concept of variable P and K applications very difficult to justify.

5. An Introduction to Albrecht Soil Analysis

Dr. William A Albrecht was an emeritus Professor of Soils at the University of Missouri who developed a system of soil analysis which revolved around balancing the soil. While it is not possible to balance all soils due to financial constraints what Dr. Albrecht found is that the make-up of the most fertile soils, in terms of nutrient balance, is the same as the make-up of humus, when it is broken down to its constituent parts. This enabled him to develop base-level requirements for the 'ideal soil' and gave a target when a soil sample from one's own farm was taken.

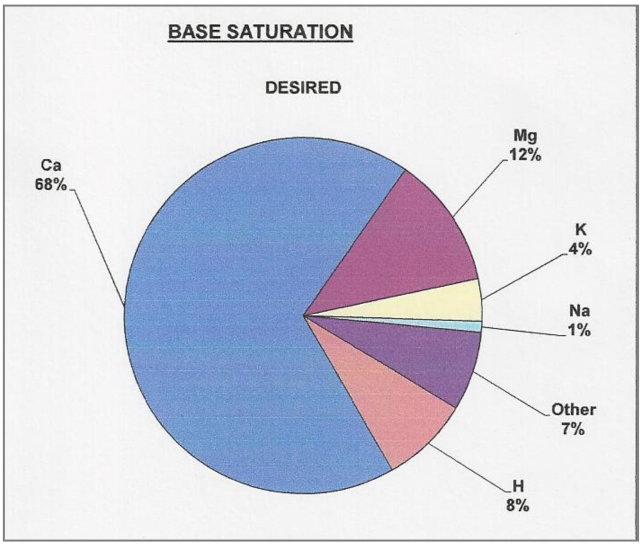


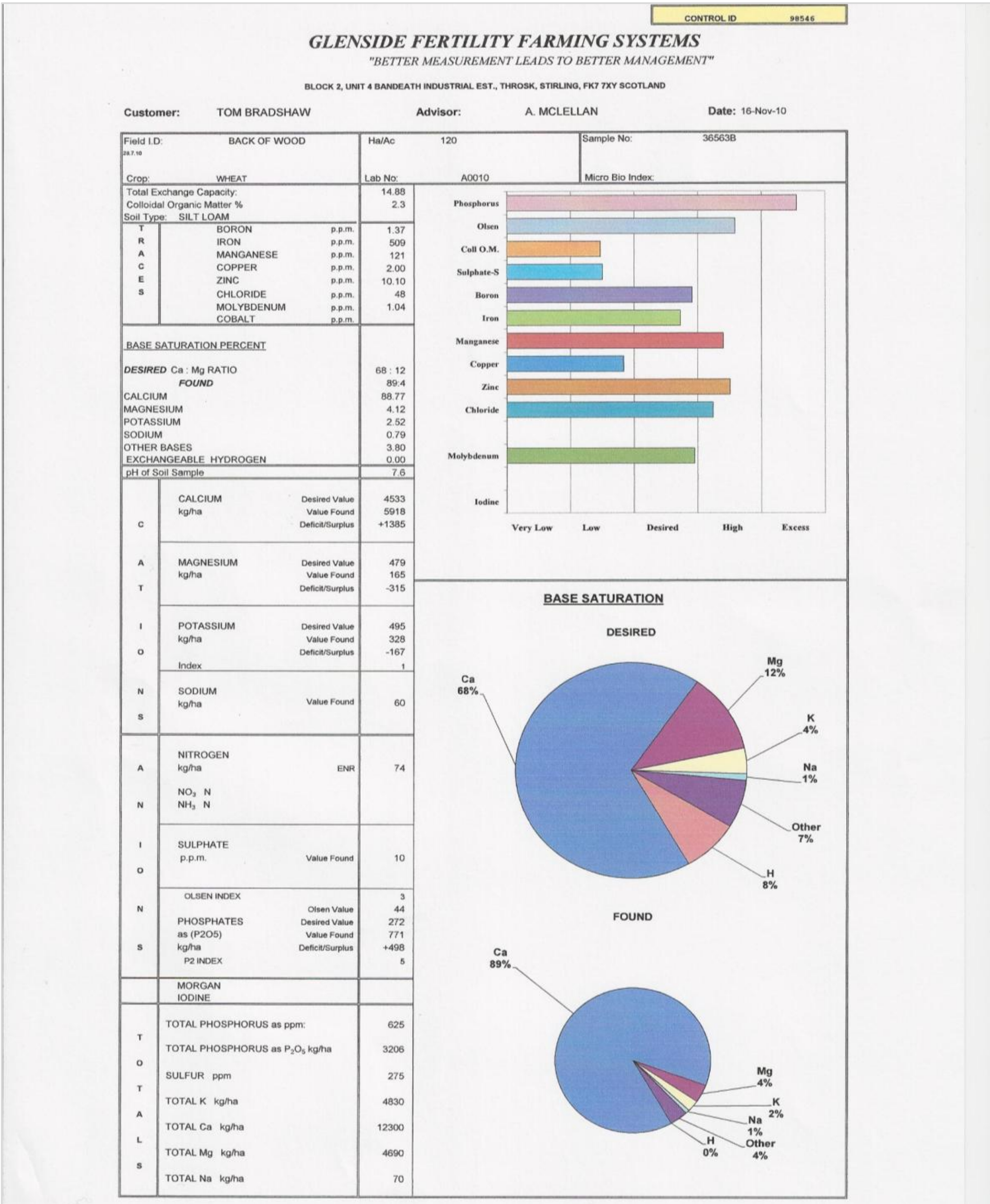
Figure 1 : The Albrecht ideal soil profile

Dr. Albrecht went far beyond this with his teachings and much of his work was not given any credit until after his death. The Albrecht Papers have been published by the Acres USA magazine and are the basis of many soil fertility programmes around the world. Dr. Albrecht saw a direct link between soil quality and food quality. His work made it clear that health stems from the soil. He drew direct connections between poor quality forage crops, and ill health in livestock. Throughout his life, Dr. Albrecht looked to nature to guide his research and learn what optimises soil, plant, animal, and even human health. Fairly early on in his research, Albrecht attributed many common disease conditions found in livestock directly to those animals being fed poor quality feeds. In Albrecht's mind, that meant forage grown on soils that were deficient in essential elements. It is for this reason that growing a crop purely based on nitrogen, potassium, phosphate and pH is not adequate and that we need to look at a much more balanced approach to crop nutrition. He also raised the question of 'What role does agriculture have to play in human health?'

I know some of the agricultural research bodies do not agree with the principles of Albrecht and don't believe that there is anything wrong with the current index system. I however would like to see some detailed soil research comparing the two different systems of soil analysis over at least a 10 year period. One of the problems with agriculture research is that most research projects are funded over a 3-5 year period. Detailed soil research and research into alternative cultivation systems (such as direct drilling) needs to be carried out over 10 years or more to draw out different results from different systems.

5.1 Results and observations from my first Albrecht test

Below are one set of results from the first soil samples that I sent to Glenside who forward the soils over to Perry Laboratories in the USA for analysis.


CONTROL ID 98546

GLENSIDE FERTILITY FARMING SYSTEMS

"BETTER MEASUREMENT LEADS TO BETTER MANAGEMENT"

BLOCK 2, UNIT 4 BANDEATH INDUSTRIAL EST., THROSK, STIRLING, FK7 7XY SCOTLAND

Customer: TOM BRADSHAW Advisor: A. MCLELLAN Date: 16-Nov-10

Field I.D: BACK OF WOOD 28.7.10 | Ha/Ac 120 | Sample No: 36563B

Crop: WHEAT | Lab No: A0010 | Micro Bio Index:

Total Exchange Capacity:		14.88
Colloidal Organic Matter %		2.3
Soil Type: SILT LOAM		
TRACES BORON	p.p.m.	1.37
IRON	p.p.m.	509
MANGANESE	p.p.m.	121
COPPER	p.p.m.	2.00
ZINC	p.p.m.	10.10
CHLORIDE	p.p.m.	48
MOLYBDENUM	p.p.m.	1.04
COBALT	p.p.m.	
BASE SATURATION PERCENT		
DESIRED Ca : Mg RATIO		68 : 12
FOUND		89:4
CALCIUM		88.77
MAGNESIUM		4.12
POTASSIUM		2.52
SODIUM		0.79
OTHER BASES		3.80
EXCHANGEABLE HYDROGEN		0.00
pH of Soil Sample		7.6
CATIONS CALCIUM kg/ha	Desired Value	4533
	Value Found	5918
	Deficit/Surplus	+1385
MAGNESIUM kg/ha	Desired Value	479
	Value Found	165
	Deficit/Surplus	-315
POTASSIUM kg/ha	Desired Value	495
	Value Found	328
	Deficit/Surplus	-167
Index		1
SODIUM kg/ha	Value Found	60
ANIONS NITROGEN kg/ha	ENR	74
NO_3 N		
NH_3 N		
SULPHATE p.p.m.	Value Found	10
OLSEN INDEX		3
PHOSPHATES as (P2O5) kg/ha	Olsen Value	44
	Desired Value	272
	Value Found	771
	Deficit/Surplus	+498
P2 INDEX		5
MORGAN IODINE		
TOTALS TOTAL PHOSPHORUS as ppm		625
TOTAL PHOSPHORUS as P_2O_5 kg/ha		3206
SULFUR ppm		275
TOTAL K kg/ha		4830
TOTAL Ca kg/ha		12300
TOTAL Mg kg/ha		4690
TOTAL Na kg/ha		70

Once I had received these results back it once again gave me more questions:

1. I believed that the soil was a heavy chalky boulder clay but the CEC was only 14.88.

2. The soil organic matter level is only 2.3%.

3. The soil is 89% calcium – I had read about lock up of triple superphosphate (TSP) on high calcium soil but never thought it would be an issue on our clay soils?

4. My attention was then drawn to the box at the bottom left of the table on the previous page; the Morgan Iodine test which shows the total amount of a nutrient held in the soil. We had 3.2t of P_2O_5 (phosphate) locked up in the soil and 4.8t of potassium (K).

5. Why was the soil working like a heavy clay when it was a medium bodied soil?

Up until this point I did not know what our organic matter level was and it had never really been a focus of our farm management. Manure from the cows had been seen purely as a waste product and was a cost for the dairy herd to dispose of. When valuing straw, to decide whether or not to sell it, the value was purely in the P and K and there was no mention given to the organic matter that was being lost. Occasionally you would hear people say that it was best to 'get rid' of the straw because of the problems it created with cultivations and slugs before oilseed rape establishment. Suddenly I had a measurement of soil organic matter levels, and the highest in the four tests I had was 3.1%, all showing that we were low in organic matter.

All my reading had suggested that within 28 days, some people say 48 hours, an application of TSP would be locked up on a soil with a high calcium content and that only 20% of the applied P would ever be available to the growing plant. We had never had a fertiliser salesman mention any other form of P fertiliser to us or discuss any of the issues involved with using TSP on a high calcium soil. I had my FACTS qualification but did not have the required level of knowledge to know that this could be a serious problem. The result was that we were using TSP as our source of P for variable rate spreading on a high calcium soil: did any of this make sense?

The most important question that was raised as a result of the tests was: how we can access the vast reserves that are locked up in the soil? If a crop requires 95kg P per year then we have enough in the soil for over 30 years of crop production and a similar situation for K.

With the information above I again continued to question how accurate and necessary our variable application methods are for P and K?

6. My study tour

Although my focus is obviously on soil there are many different factors that affect the way the soil functions, many of which we are only just beginning to understand. These range from chemical applications and the interaction they can have with soil microbes, through to machinery wheelings and GPS control. This meant that while on my study tour I looked at best practice on farm as well as meeting with soil scientists, sustainable agricultural consultants and biotechnology companies.

Germany – June 2011, 2 weeks

In Germany I was trying to compare how they use the variable application with the N-Sensor compared to how we are using it here in the UK. I also went to look specifically at a form of fertiliser injection which manipulates the way the plant grows, Controlled Uptake of Long-term Ammonia Nitrogen (CULTAN).

Australia – October/November 2011

Australian farmers operate in a very harsh climate where the prospect of crop failure is a real possibility. Without the safety net of subsidies to fall back on they have to be very efficient to maintain profitability. In the 1970s in the UK there was a lot of fertiliser placement used at the time of drilling, which I believe will result in much more efficient use of the fertiliser, and this is a system that is still widely used in Australia. There are also some world renowned soil scientists who operate from Australia and while there I successfully gained a Certificate in Sustainable Agriculture.

USA – December 2011

I visited the USA on a roundabout route to Argentina while on my way from Australia to attend a conference organised by Acres USA where many of the top consultants from America were presenting.

Argentina – December 2011

While in Argentina I spent a couple of days with Monsanto to look at the role of Biotech crops and the influence they are having on production. I went and looked at best practice on farm and visited one of the pioneers of direct drilling in South America who also farms in Paraguay. I then visited a company producing biological products, particularly seed treatments, that are improving fertiliser use efficiency and unlocking the soil reserves.

7. Findings from my study tour

- The implementation of the Albrecht soil system leads to an improvement in herd health and eventually leads to the farmer converting to organic production. A case study from Terry Hehir is included in chapter 8 on the following page.

- For sustainable crop production systems in UK arable farming we have got to start actively managing for organic matter content (carbon content) of soils and the massive benefits that this can have on water retention, reduction of leaching, soil biology and therefore nutrient recycling, workability and profitability. This is discussed in chapter 9

- The use of cover crops to improve organic matter content and all the associated benefits that this brings is discussed in chapter 9.1.

- The role of direct drilling in improving soil biology and reducing erosion needs to be conveyed to the wider agricultural community. A case study from Roberto Peiretti, one of the pioneers of direct drilling in Argentina, is included in chapter 9.3.

- A greater understanding of the use and uptake of nitrogen by plants is required to improve efficiencies of usage. The critical timings for nitrogen fertiliser to stimulate maximum seed set needs to be researched and the role that humic and fulvic acid could play in improving efficiency of uptake. The use of Nitrogen is discussed in chapter 10.

- The need for seed treatments for legume crop production in the UK is not being fully explored and therefore they are not being utilised. The impact this could have on yields and nitrogen fixation could be of major significance to arable rotations. A discussion of biological seed treatments and an outline of a trial of a rhizobium bacteria seed treatment on my farm this spring can be found in chapter 11.

- The role of crop monitoring to assess nutrient requirements and the health of the crop needs greater research and understanding, particularly at a farm level. This is discussed in chapter 12.

- It is possible to make the locked up nutrients in our soil available but this relies on having active soil biology and gaining a greater understanding of the functionality of soil.

- The use of mycorrhizal fungi as seed treatments to access the locked up P needs to be researched and understood.

8. Albrecht and organic dairy production – Terry Hehir

I visited Terry Hehir NSch at his farm in Wyuna, South Australia. This area of Australia has been through one of the longest droughts in memory over the past 7 year period but it does finally appear to have broken and production prospects are improving. One of my stand-out memories of this visit is that over this very difficult period, while many of Terry's neighbours were going out of business, he has been able to consolidate and even expand their land holding. This is a real credit to Terry and Pauline, the team around them and the system of production that they have chosen to follow.

Terry started to explore soil fertility issues on his conventional dairy farm back in the early 2000s. At this point in time the farm was a very high input, high output dairy farm with all the associated medicinal inputs for lameness, mastitis, and fertility. Although I cannot be sure, I assume that the farm was producing top quartile results for the industry and was clearly managed to an extremely high standard. Terry was sitting on dairy industry boards at a national level and was a very well respected dairy producer. The soil type was typical of the area, very shallow (2-3") and not very moisture retentive.

When Terry came across the Albrecht Fertility System he immediately started to implement some of the recommendations across his farm. Over a 10 year period of following this approach the soil has been transformed, from a shallow soil lacking life to a highly productive, deep red soil (over 12") with abundant soil life and worm activity. This is shown in the picture below.

Terry believes that he is growing his topsoil at a rate of 1” per year. Since adopting the Albrecht approach Terry has proved that it is possible to balance a soil that starts with high magnesium levels and low calcium levels. The two key elements from his soil results for the same field are shown in the table below.

	Calcium %	Magnesium %
Albrecht Desired	68	12
Field A 2003	50	30
Field A 2010	65	15

To achieve these transformations he has followed the strict Albrecht advice from a recognised consultant and has imported large amounts of calcium limestone to improve the calcium content of the soil. I will hear many asking ‘what is the cost of all this?’.

The answer is quite the opposite; far from there being a cost to this business the implications have been huge and far beyond levels that were ever anticipated. Once Terry was on this road he started to realise that his cows were not getting the same lameness problems that they had been previously. This was also true for mastitis, and the level of spend on antibiotics was reducing dramatically. At this point Terry decided, against all advice, that they may be able to convert the herd to organic principles. The herd health was far better than it ever had been, the grass growth the same (although the leys now include many different species of grass and clover and lucerne is also being grown) and now the herd operates under an organic system. Last year they were hoping to produce as much milk as they ever did under a conventional system, which is quite some achievement.

When Terry and the team set off down this route of soil fertility, he had read about the benefits of feeding nutritionally dense forage, rather than forage that is high in nitrate, and all other associated health benefits but he had never had any intentions of turning organic. This is an example of how the Albrecht system adopted on a large scale, 600 cows, and managed by a very professional business can have a dramatic impact on profit, lifestyle and production.

9. Soil Organic Matter

Organic matter is vital for the physical, chemical and biological functioning of soils. Organic matter is fundamental for soil structure. It helps bind soil into bigger particles to produce tilth and also helps prevent soil slumping and soil erosion. It is estimated that in UK arable soils between 1980 and 1995 around 18% of soil organic matter has been lost and that annually in the UK we are losing 2.2 million tonnes of soil through erosion *(Parliamentary Office of Science and Technology).* To put the figure above into context, that means between 0.1-0.3t/ha per year of soil is being lost. Many UK arable soils are now well below the target levels of 3-5% organic matter, although until I received my Albrecht tests through I didn't have a measure of what level ours were. Organic matter levels of around 5% are likely to supply around 125kg/ha of nitrogen to the growing crop. Not knowing is even more worrying than having a low test result because it shows that it is something that is not being managed. None of these figures paints a very sustainable picture of current arable farming practices.

As we remove crop and crop residues, organic matter is being exported from the field. This should be a conscious decision from the farmer and a realisation that we are not just losing the chemical components of P & K etc but also the physical characteristics of the organic matter. This straw would have been decomposed into humus by the soil biology. As organic matter is broken down it slowly releases nutrients in balanced quantities that are readily plant-available. Organic matter is the feed source for the soil microbiology; bacteria feed on green material while fungi break down more complex lignified organic matter. The humus produced by the fungi is a very stable carbon which increases the carbon content of the soil and could have a positive impact on climate change. The carbon produced is in a very stable form (the term carbon content and organic matter content are interchangeable with a simple calculation: Carbon = Organic Matter x 0.56).

If the decision is taken to remove crop residues then a conscious decision should be made to replace this organic matter. Sources of soil organic matter are shown below:

1. Plant roots
2. Crop residues
3. Decomposing soil micro-organisms and animals
4. Farmyard manure
5. Sewage sludge
6. Cover crops
7. Composts

Humus acts as a sponge and holds its own weight in water within the soil profile and this is in a very available form as it is directly next to the plant roots. If soil organic matter levels are increased by

1% then 6” of topsoil can hold an extra 170 000 litres of water. In a climate which appears to be changing and where weather events become more extreme this could make a big difference to production in the drier parts of the UK. Humus also provides a very available source of nitrogen to the plant and large quantities of phosphate and sulphur.

Not only are soil carbon levels reduced by removing crop residues but also by the oxidisation of carbon when soils are cultivated; this is even more a problem if soil conditions are too wet at cultivation.

9.1 The role of cover crops

In agriculture we have one free energy source, the sun. Through photosynthesis this energy source is harnessed and converted into food, feed and fibre. The more of this energy we can intercept the more likely we are to create a sustainable farming system. When we don’t have plants growing to capture the solar radiation it can actually harm the soil biology, especially in months of high solar radiation; in the UK I am particularly thinking of August and September. The purists from conservation agricultural movements would not like to see a period of greater than 2 weeks where there is no crop growing and the soil is warm enough for the soil biology to be active, namely above 6°C.

Cover crops do so much more than just provide organic matter. They can be used to correct soil structural problems, improve soil biology, suppress weeds and the acidic root exudates of specific plants can solubilise locked up nutrients from within the soil. They also provide a feed source to the soil biology. It is thought that over 30% of the sugars produced through photosynthesis are exuded through the root system to feed the soil biology and maintain the rhizosphere. It is also believed that through these root exudates the rhizosphere is able to detect which nutrients the plant is short of and actively seek out those nutrients, a truly symbiotic relationship. I know this will seem an alien concept to many but we really are only just beginning to understand the role and functions of the different species within the soil food web.

When choosing a cover crop it is important to think about the aim of crop that is being planted. Below are examples of different cover crops and the specific use they may have:

- Nitrogen scavengers: cereal rye, sorghum, rye grass, oats, radish, mustard, buckwheat
- Erosion control: cereal rye, barley, sorghum, oats
- Soil building: vetch, clover, ryegrass, oats
- Fast growth: buckwheat, oats, peas, mustard
- Nitrogen fixation: peas, spring beans, lucerne, vetch
- Weed suppression: oats, cereal rye, buckwheat, vetch, mustard
- Phosphate solubilisers: oats, buckwheat
- Nematode suppression: brassica family

Many advisors are now recommending the mixtures of a minimum of three different species within a cover crop because they have different rooting depths, perform different roles and generally on farm the result is far greater than the sum of the parts. On livestock farms it is also commonplace to graze the cover crops rather than return them to the soil. Another important consideration is what crop is going to be following the cover crop, and has preceded the crop, to try and avoid disease carryover. It is also important to consider whether or not the cover crop roots will be a host to the desired soil biology. Mycorrhizal fungi cannot live on brassica roots but are critical to the release of the locked up phosphate. This is an example of why it may be advisable to avoid growing brassicas on their own as a cover.

In France (Brittany), Frédéric Thomas has been growing cover crops for over 10 years and he is now aiming to produce 10t/ha dry matter between a mid-July harvest and early October sowing. These cover crops can capture around 140kg/ha of nitrogen, reducing the amount of nitrate left in the soil that can be leached, and as this organic matter is broken down the nitrogen captured becomes available to the growing crops.

As a result Frédéric Thomas is now applying less fertiliser year on year and is farming far more profitably and sustainably.

Gary Zimmer, whom I met in America at the Acres USA conference, analysed a cover crop of clover before incorporation and the nutritional values are shown in the table below:

Clover cover crop		
Dry matter yield	6.5	t/ha
Mineral	%	kg/ha
Nitrogen	3.8	247.0
Calcium	1.7	110.5
Phosphate	0.3	20.2
Magnesium	0.5	32.5

With nitrogen costing £1/kg the financial contribution made by the cover crop in reducing costs for following crops is considerable. It should be pointed out that not all of this nitrogen is available to the following crop, but becomes available as the organic matter is broken down. The other thing not taken into account is the amount of nitrogen fixed in the soil by the clover crop which is plant available.

9.2 The role of compost in increasing organic matter levels

While in Australia I visited Cameron McKellar, based at Inverary Downs, Spring Ridge, New South Wales. Cam has been following biological farming practices on his farm for about the past 10 years. At the point that Cam decided to adopt a different management approach on his farm, urea fertiliser prices had gone to over $800AUS and he was asking some searching questions about their long-term prospects. Biological farming is really bringing the best of organic farming principles together with best practice from conventional agriculture, while utilising alternative inputs to try and promote soil and plant health. Cam's aim is 'to produce food with nutritional integrity in a biological manner, holistically enhancing his soil and environment at every opportunity'. Over the last two years Cam has been awarded 'The Australian Greening Initiatives in Agriculture' and 'The Carbon Cocky (Farmer) of the Year' for the work he is doing with compost to increase the soil organic matter levels. Over a 5 year period of using compost made on farm he has been able to build his organic matter levels by around 1%. This is not down to vast quantities of compost as it is applied at relatively low rates, 10-12t/ha, but it is obviously having a greater impact on promoting the soil biology with the composts acting as a feed source and inoculum.

The picture opposite is a picture of Cam with a soil moisture probe. This is very similar to a penetrometer. In this field we were able to push the 1.25m rod down to full depth without hitting any compaction. This was a real eye opener to me and obviously shows the depth of the soil but even so I wonder if this would be possible on a soil of similar depth in the UK?

I don't believe that it is possible or necessary in the UK for every farm to try and import compost. In any case I would only recommend importing very well made compost that has a relatively low C:N ratio, otherwise nitrogen will be locked up while the compost is broken down. Also it should not contain any plastic, which a lot of green waste compost does. My belief is that with the use of cover crops, we can achieve many of the benefits of compost, but we also keep an actively growing root system with the many benefits that this brings with it.

9.3 The role of conservation agriculture in reducing soil erosion

While in Argentina I visited Roberto Peiretti who is responsible for managing over 25000ac of land in the Cordoba region. He farms in partnership with his wife and daughter. As well as running a very professional farm he has an independent agronomy company that carries out trials as well as giving agronomy advice. Roberto tells the story that just over 30 years ago he walked into the local blacksmiths, where most of his tillage machinery was being manufactured, and said that he had decided he no longer wanted to plough and cultivate anything but instead he wanted a drill that could drill straight into the previous crop. His reasons for this were primarily that he was experiencing very high levels of soil erosion from his old system and that he did not believe this should happen. Since adopting conservation agriculture, which in its purest form is direct drilling, soil erosion has become a thing of the past, yields have increased and the soil is functioning again resulting in lower levels of nitrogen use. He is producing 12-14t/ha of corn (maize) on only 125-150kg/ha of applied nitrogen. Conventional growers in the USA are using over double to achieve similar yields. In reality it means that the nitrogen fixing bacteria within the soil were fixing over 150kg/ha of nitrogen per year. The benefits of direct drilling for Roberto are not just the cost savings from reduced fuel usage, reduced tractor hours, moisture conservation and increased water holding capacity, but the knock on effects that develop with time as the system develops: such as increased nitrogen fixation (from atmospheric nitrogen), increased yields and reduced inputs.

The two pictures on the following page were both taken at exactly the same place and show the benefits over a relatively short period of time from changing the management practices. I just ask you to think about the amount of topsoil being lost annually in the UK and then refer you to a quote I heard while in America, although the source is unknown:

'We stand in most places on earth, only six inches from desolation, for that is the thickness of the topsoil layer upon which the entire life of the planet depends'

Picture 1: Taken in 1998 when the field was under a plough based cultivation system

On next page see picture of same field taken 13 years after converting to direct drilling.

Picture 2: Taken in 2011, 13 years after converting to direct drilling

10. Understanding nitrogen

As a farmer in the UK one of my biggest frustrations is the lack of knowledge and research I have available to me about the uptake of different forms of nitrogen, and the different efficiencies that they may offer. The knowledge that we do have available is very simplistic and I often feel that the results put forward are biased to one form or another depending upon who has done the research. I regularly feel that if farmers see a good crop in the field the temptation is 'to give it a bit more' because of the fear of holding the crop back. I don't recall ever receiving a leaf tissue test result back that has showed low nitrogen levels.

Lack of nitrogen is believed to be one of the most limiting factors in crop production yet the atmosphere contains 78% nitrogen. In a healthy, biologically active soil, more nitrogen is fixed from the atmosphere, through many different micro-organisms, than in a 'dead' soil. The amount of nitrogen fixation is strongly associated with the amount of soil organic matter.

While in Australia I did a Certificate in Sustainable Agriculture run by Nutritech Solutions. On the first day of this course we went through all the major nutrients and while we were going through nitrogen there were some very interesting discoveries.

- Overuse of nitrogen will often result in calcium and potassium deficiency.
- Overuse of nitrogen also results in reducing levels of soil carbon. In very simplistic terms, because carbon is present in all bacteria at a C:N ratio of around 5:1, when excess nitrogen is applied there is a feeding frenzy. The available nitrogen results in a dramatic multiplication of the bacteria that sequester nitrogen, which means that carbon has to be converted out of organic carbon into the bacteria, allowing for the nitrogen molecules in the bacteria to be balanced by the carbon molecules at the ratio of 5C:1N. Further down the food chain,as the bacteria are eaten by protozoa which have a C:N ratio of 30:1, some nitrogen is released which is available to the plant but the carbon is maintained within the protozoa.
- Nitrogen in the plant should be taken up as nitrate during the vegetative stage and ammonia during the reproductive stage.
- The use of humate (carbon based products originating from Leonardite coal) granules to stabilise urea and ammonia applications should be considered to maximise efficiencies.
- The uptake of foliar urea can be tremendously enhanced by mixing with humate granules resulting in massive efficiency gains, up to 150% increases.

As more focus falls on the agricultural industry to improve our environmental profile we have got to improve the efficiency of nitrogen use and to do this we require some detailed research to be carried out.

1. Is liquid N more efficient than solid N?
2. Can we tailor the timings of nitrogen application to stimulate increased seed set?
3. Is ammonium nitrate a more efficient source than urea or do they both have preferential timings?
4. Is ammonium sulphate a better all round product than any of the above?
5. Can we improve the efficiency of liquid urea in the UK by mixing with humates?

Of the research that I can find, one study reveals that ammonium nitrate may be 23% more efficient than urea while an annual study carried out by The Arable Group reveals no statistical difference.

At a conference in the UK recently I was horrified to hear one of the UK's leading plant pathologists point the finger at large scale arable farming for the reason that yields have plateaued over the past 15 years due to poor timeliness of application of fertiliser and fungicides. If we were armed with knowledge of the correct timings and the correct quantity and type of product plus the knowledge it was going to give an economic response then I don't think any farmer, large or small, would choose not to maximise profitability.

I'm afraid that I haven't come back with the answers but I hope to be able to stimulate some research and we will certainly be trialling the use of humates.

11. The role of biological seed treatments

We know that the rhizosphere of many arable soils in the UK is bacterially dominated rather than having a balance of bacteria and fungi present *(Franklin, 2011).* Research has also shown what an important role these fungi play in releasing the nutrients that are tightly bound in our soils. In Argentina I visited a company called Rizobacter that focuses on naturally synthesised biotechnological products. They have a range of products from surfactants and wetters through to fungal seed treatments. The company philosophy was extremely impressive and the research and development programme was excellent. The facilities that the company had invested in for the R & D programme were some of the most modern I had seen, including climate controlled glasshouses with artificial light to enable soya beans to be grown through to maturity in a little over 6 weeks for trial purposes.

When I arrived one of the first questions I was faced with after telling them what crops we grow was:

'You must be using rhizobium seed treatments on your legumes?'

This is also a question I had been faced with in the very early stages of my trip through Australia and I was embarrassed that the answer was no, and that I had never heard of treating legumes with this bacteria. It is commonplace throughout Argentinean agriculture to use such a seed treatment with over 85% of soya beans treated with rhizobium bacteria. It is also commonplace in Australia and the USA. I ask the question: are we in the UK really at the forefront of agricultural development?

Each legume requires a specific species and strain of rhizobia. Commercial inoculums are labelled according to the plant species for which the rhizobia are highly effective. Successful nodulation and effective nitrogen fixation requires the correct inoculants. For example, the rhizobium species that nodulates lucerne will not nodulate dry beans or soyabeans. To tell if a legume crop is successfully fixing nitrogen through nodulation the plant roots should be pulled out and the root nodules should be bright pink in colour when they are cut open. If the nodules are very pale they are not likely to be fixing any significant quantities of nitrogen.

In the trials that Rizobacter has carried out with rhizobium seed treatments the results are very significant. The yield of the soya beans is only slightly higher, up to 20%, but the nitrogen fixation increases by 150-300kg/ha, with some soya bean crops fixing over 400kg/ha of nitrogen. Obviously this has huge impacts on nitrogen requirements for following crops.

A list of biological seed treatments

1. Rhizobium – responsible for nitrogen fixation by legumes.

2. Pseudomonas bacteria – increase phosphate concentration around the plant because they have very high P concentration so they have to solubilise phosphate to reproduce and survive. The pseudomonas produce organic acid to make available organic P and produce phosphotase to solubilise P from organic matter. These are currently being used on wheat and corn with the best results on soils with low P availability. They are also linked with

increasing root mass on all soil types and improving drought tolerance.

3. Mycorrhizal fungi – These seed treatments can be used on any crop other than brassicas. The mycorrhizal fungi are extremely important for two reasons. Firstly they are able to access the soil reserves of phosphate, and secondly they effectively increase the size of the root mass because they have a symbiotic relationship with the roots and root exudates and so have the effect of increasing the surface area of the roots allowing access to greater nutrition and water.

Rizobacter are also developing a product which is currently being used in soya beans, **Signum**. Signum is a biopreparation that acts as a generator of molecular signals that activate early metabolic processes in bacteria and plants. Signum, through biosignal communication, prepares plants to interact with the surrounding and have better resources to develop:

- Promotes symbiotic association with rhizobium bacteria, causing higher rhizosphere activity and more effective nodulation, which allows plants to optimise biological nitrogen fixation.

- Stimulates the interrelation with different soil-beneficial micro-organisms which allow further advantages at inoculation.

- Activates mechanisms to resist abiotic stress conditions: low temperatures, drought and soil acidity.

- Induces defensive responses in the interaction with harmful micro-organisms.

11.1 Trials of Rhizobium seed treatment

I must thank Rizobacter for the effort that they have gone to because since returning to the UK we have continued discussions and they have produced a rhizobium seed treatment suitable for Vicia Faba. We now have a trial drilled this spring with around 2ha of treated seed alongside 3ha untreated seed all drilled on the same day. We very much look forward to seeing how the crops develop through the spring and any benefits that this seed treatment may provide.

12. Crop monitoring

In general I think farmers are good at soil testing and getting soils analysed. I may not believe that the tests that are being carried out are the correct ones or that the results show all the information required but I do think they are being done. This may be because it gives farmers an excuse to invest in new technology for variable rate spreading, it may be because the colourful maps provided look good on the shelves in the office, or it may be because the farmer is genuinely interested in soil and the limitations that low indices provide. The other reason could be that legislation dictates that we have regular soil analysis for ACCS and Soil Protection Review.

I therefore find it very odd that growing crops are not regularly analysed to check that what is shown to be available from the soil test is available to the growing plant. Obviously soil tests are very important but the most important information is what the plant is able to access. One example that is regularly talked about is that magnesium indices can be very high but it is still not available to the plant. By the time these plants are showing visible symptoms, yield loss is going to be irretrievable and the damage has been done. Regular tissue testing through the season can show if nutrients are in decline or in shortage, so that deficiencies can be corrected before the plant has shown clinical symptoms of deficiency. Most deficiencies can be corrected with reasonably inexpensive foliar applications.

I can't understand the need for prophylactic spraying of nutrients when tissue testing is very simple and inexpensive. If tissue tests show the same results for 3 years then it can generally be assumed that the nutrient in question will be required as a foliar every year.

As a general rule it is best to test crops before they enter periods of rapid growth, for instance oilseed rape would be tested just before stem extension and wheat would be tested at GS 30. If low levels are showing these can be retested once treatment has been carried out, or in the case of elements like boron in wheat which can be toxic, they can be resampled before the key growth stage (GS33) to make sure that the deficiency is still showing.

Leaf tissue samples cost around £15 per sample and there are numerous laboratories that are offering the service. NRM and Lancrop Laboratories are two examples. One sample would probably be taken for each different soil type.

There are also other crop monitoring tools that can be used to assess the health of the crop in the field, ranging from a nitrogen tester through to the pH of the sap and the sugar content of the leaf tested with a Brix meter. The use of these tools in broad acre crops is only just being explored but if they can give us accurate assessments of the nutrient requirements of crops in real time in the field then in the future they will be able to help us tailor applications and timings to the crop's needs.

13. Conclusions

1. The Albrecht system of soil fertility and soil balancing, when carried out properly, enhances the quality of forage, which can have a knock on effect on animal health and animal management systems. I believe this can also be influential in arable farming systems.

2. Measures of Cation Exchange Capacity (CEC) and Soil Organic Matter should be shown as standard on soil analysis results. In the case of organic matter once it is being measured it can be managed.

3. The future of soil fertility and sustainable production systems revolves around managing soil organic matter and conveying to farmers the benefits associated with this.

4. The only free source of energy in a farming system is solar radiation and through the use of cover crops we can capture more of this radiation and utilise it to improve production systems, reduce leaching, improve nutrient availability and increase biological activity.

5. Biologically based seed treatments are having a massive impact on agricultural production worldwide and need to be trialled and adopted in the UK if trials are successful.

6. Soil erosion can be reduced in the UK by the adoption of conservation agriculture techniques. This does not have to mean direct drilling but it does mean trying to maintain ground cover whenever possible.

7. Leaf tissue analysis is an important means of trying to maximise production efficiencies and should be widely adopted in farming systems from intensive grassland production through to arable production.

If anybody requires further information on any of the subjects covered within this report then I would be very happy to discuss these in more detail and can be contacted at:

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14. Recommendations

1. The current FACTS advice system is a great tool for farmers to gain an understanding of basic soil and crop nutrition but should not be a foundation for trying to maximise productive efficiencies and minimise environmental impact. A more detailed qualification with a greater focus on soil fertility issues and the role of soil biology in maximising productivity is required.

2. A detailed comparison of the Albrecht soil fertility programme and current best practice, recommended in RB209, needs to be carried out as a long-term project. Soils research that was carried out in the 1970s and 1980s on soils that were probably much higher in organic matter, and therefore biological activity, should be omitted and the research should be started from scratch. Included in this research should be a detailed analysis of the quality of the crop or forage produced under the different systems.

3. A detailed, long-term, research project into different cultivation strategies and the effect these have on soil erosion and organic matter content should be carried out to give guidance to farmers when looking to adopt different cultivation approaches.

4. A reappraisal of research into nitrogen use and how different forms of nitrogen fertiliser impacts the efficiency of use needs to be carried out so that as an industry we can try and improve our efficiencies and maximise margins.

5. Knowledge transfer within the industry needs to be improved so that results from scientific research can be effectively passed down and implemented by grass roots farmers.

6. The role of humates in improving nitrogen use efficiencies needs to be fully researched and understood.

15. After my Nuffield Study Tour

Since returning from my study tour and trying to analyse how to implement some of the new knowledge that I have gained we are starting to put some changes into place. I am employing a company to carry out a different technique of precision soil sampling across all the land farmed. Once different soil types have been assessed each individual soil type will then have a full analysis carried out with an Albrecht test. This will assess the soil variation across the farms and allow for a different form of precision application of nutrients than what we have currently been using.

I am carrying out a full appraisal of all the machinery currently used on the farm to assess if it is fit for purpose or if the machinery is ruling the cultivations required in front of it. When travelling around the world it was amazing to see how low the horsepower requirement is on many of the farming systems that I was privileged to see. This is likely to lead to some changes in the machinery line-up in the coming seasons.

To make better use of nutrients that are applied I am convinced that the placement of fertiliser at drilling is going to have a big impact. I have looked at the main functions that we require from a seed drill and these include:

1. Being able to drill in all situations from direct drill through to plough based cultivations
2. Seed and fertiliser placement
3. Low horse power requirement per metre
4. Low soil disturbance
5. Excellent contour following, and seed placement

We are now assessing the drills in the marketplace and this will almost certainly result in our changing seed drills over the next couple of seasons.

Beyond this we continue to assess the impact of cover cropping on our soil, particularly before spring cropping but also between 1st and 2nd wheat, and we will probably have sheep grazing stubble turnips this coming winter before spring barley.

I am continuing to read and explore the very complex subject of soil fertility with the aim of continuing to improve efficiency of use in our farming business.

16. Thanks

There are many people who have made it possible for me to go around the world on my Nuffield Scholarship and I'm sure it will not be possible to name them all. So to anybody who has helped in any small way it really has been appreciated and has given me the opportunity of a lifetime. There are however some who require special thanks:

The Nuffield Farming Scholarships Trust for deciding to put faith in me and I hope I have not let them down

My personal sponsors, **Alan and Anne Beckett**. I am truly grateful for all the good work that you have put into the Nuffield organisation and your sponsorship of my award. You don't truly appreciate what Nuffield has to offer until you are on the inside and you gave me the opportunity.

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