

A Nuffield Farming Scholarships Trust Report

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Breaking the wheat yield plateau in the UK

Jake Freestone

July 2014

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A Nuffield (UK) Farming Scholarships Trust Report



Date of report: July 2014

"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	Breaking the wheat yield plateau in the UK.		
Scholar	Jake Freestone		
Sponsor	Central Region Farmers Trust		
Objectives of Study Tour	To investigate the techniques employed by wheat growers around the world to increase yields.		
	To understand the limiting factors to high yielding wheat crops and how these factors can be minimalized.		
Countries Visited	United Kingdom Canada United States of America Mexico New Zealand Ireland		
Findings	Improved soil management through zero tillage, longer and more diverse rotations, cover crops and livestock integration are the key factors to increase yields and are in the farmer's own control.		
	Although out of a farmer's direct control, understanding the impact of climate change, rainfall and genetics, has a vital role to play in the realisation of yield potential.		

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DISCLAIMER

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

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Nuffield Farming Scholars are available to speak to NFU Branches, Agricultural Discussion Groups and similar organisations

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1.0. Introduction

I have to thank my godfather, Martin Riley, for opening the farming door to a city boy and giving me the opportunity to be by a career inspired in agriculture. From the age of 12 I visited his farm, milking Jersey cows, and from that moment onwards I never considered a career in anything other than agriculture. I graduated from Seale Hayne Agricultural College in Devon in 1995 with a 2:1 degree in Agriculture and on graduation I was awarded the RABDF (Royal Association of



Me, Jake Freestone

British Dairy Farmers) Dairy Student of the Year. Later that year I started work for the Duke of Buccleuch as an Assistant Farm Manager at BQ Farms on the Boughton Estate, near Kettering in Northamptonshire. After spending nearly four years in Northamptonshire I moved on to work for Velcourt, managing farms in Kent, Gloucestershire and Lincolnshire, before starting my current role, as Farm Manager at Overbury Farms on the Gloucestershire and Worcestershire border, in 2003.

The mixed farm extends to over 1,500 Ha on three different soil types, specialising in combinable crops and lamb production. Some land, with irrigation, is let out annually for vegetable and potato production. The permanent pasture supports a ewe flock of 1100. The farm entered into a 10 year Higher Level Stewardship agreement in 2011 and later that year became the 39th LEAF (Linking Environment and Farming) Demonstration Farm.

In 2010 I was runner-up in the 'Farmers Weekly' Farm Manager of the Year Competition and in 2013 presented a paper at the Oxford Farming Conference entitled, 'Will Precision Farming change the face of UK agriculture?' Many aspects of precision agriculture are practised on the farm including guidance, variable rate seeding, fertiliser and yield mapping, to optimise crop production.

I am a strong believer in positively communicating what we do (as farmers), not only within our own industry but also to those on the outside looking in. I am very active on social media, believing that it is a great opportunity to inform, educate and inspire our customers, the general public and the next generations of farmers.



2.0. The importance of increasing wheat yields

Nuffield Inspiration for mv Farming Scholarship came after a visit to Rothamsted Research Centre with the West Midlands Crops Board of the National Farmers Union in February 2012. I was inspired by the forward thinking of Rothamsted's founder, Sir John Bennet Laws, when he set up the Broadbalk experiment in 1843, replicating trials of wheat plots which have been running consecutively for over 170 years. The publication of the Foresight Report, headed by Professor Sir John Bennington, indicated to me that, as an agricultural industry, we needed to explore methods of increasing onfarm yields. These yield increases must not With a growing world be at all costs. population, estimated to be at 9.6 billion people by 2050 (United Nations Report - World

Population Prospects: the 2012 Revision), and



Rothamsted continuous wheat trial plots

with critical resources such as land, water and energy becoming increasingly under pressure, we need a food and farming system that can deliver resilience to our businesses and stabilise the *production and therefore supply of food. (Appendix 1).* See also Appendix 2 *(Climate Change Committee predictions)*

"The challenge for global agriculture is to grow more food on not much more land, using less water, fertiliser and pesticides than we have historically done" – Sir John Beddington UK Government Chief Scientific Adviser.

Worldwide, wheat provides 1/5 of human calories. Annually the UK grows approximately 15 million tonnes of wheat, with current yields averaging 8.4t/Ha. But since the 1980s the annual rate of yield increase has declined (Appendix 3) creating what is known as the 'Wheat Yield Plateau'. Wheat is the second most widely grown cereal crop in the world, after maize, with an estimated annual production of 650 million tonnes. Consumption of wheat is estimated at 700 Million Tonnes (Appendix 4).

Wheat is the largest single crop on the farm that I manage and the financial return it generates plays an important role in the profitability of the farm business. I wanted to learn more about increasing wheat yields in different climatic regions of the world and to explore different growing techniques. I wanted to talk to the best wheat growers in the world to see what lessons I could learn, to use at home and then to share with other growers.



3.0. My study tour

My research started where the inspiration for my Nuffield Farming Scholarship began, at Rothamsted, to hear first hand about the direction and thinking behind the 20 x 20 research project. I followed this up with visits to Canada, the United States, Mexico, New Zealand and Ireland.

February 2013	United Kingdom, Rothamsted, James Hutton Institute, John Innes Centre, NIAB/TAG, ADAS, Cranfield		
	My first thought when investigating a programme for my Nuffield Farming study tour was to go to Rothamsted where the project "20:20 Wheat" is one of the main research topics undertaken with funding through the BBSRC. (Biotechnology and Biological Sciences Research Council). I wanted to visit UK research facilities, to appreciate where our current research and industry ideas were being developed.		
March 2013 and June 2013	Canada, Ontario, Alberta, Saskatchewan		
	I wanted to visit the prairies of Canada to look at the production of wheat grown in short growing seasons and the use of genetically modified material in the crop rotation. I was also very keen to visit the Global Institute for Food Security based at the University of Saskatoon.		
June - July 2013	United States, Oklahoma, Idaho, South Dakota, North Dakota.		
	My visit to different States within America sought to uncover answers regarding zero tillage, precision farming, cover cropping and livestock integration into the arable rotation.		
July 2013	Mexico – CIMMYT		
	The home of the Green Revolution and Dr Norman Borlaug makes this a mecca for wheat researchers from around the world so a study about increasing wheat yields would not have been complete without a visit.		
November/December 2013	New Zealand		
	New Zealand farmers are the past and current holders of the		

Guinness Book of Records entry for the highest wheat yield. With a similar climate to the UK and with farmer-driven



research a visit here is likely to provide many of the agronomic answers to increasing wheat yields in the UK.

June 2014

Ireland

For the period 2008-2011 Ireland had the highest national wheat yield average in the world at 8.93t/Ha. I wanted to explore how these crops were grown, what cultivation strategies were used in a very wet climate, and what threats to future yield increases were expected.



4.0. "20 by 20": fact or fiction?

The quote "20 by 20" refers to Rothamsted Research Station's stated aim of achieving wheat yields of 20 tonnes to the hectare within 20 years.

Rothamsted has led the research on this subject and the target they have set themselves is a challenging one - to more than double the grain yield of UK wheat per hectare before 2032. Leading the project is Professor Martin Parry who stated "Wheat is the world's number one staple crop and has not benefited from the attention afforded to corn and soya beans in recent years".

The project is aiming to look at four specific areas of study and innovation:

Maximising yield potential:

Wheat yield is expressed as the final grain yield of a genotype (variety) when grown under optimal conditions, in an environment free from competition, and biotic (living e.g. fungal/pest) and abiotic (non-living, e.g. drought) stresses. To increase yield potential, the scientists at Rothamsted will be looking to increase photosynthetic efficiency, alter crop canopy and root architecture, modify seed development and enhance nutrient utilisation efficiency.

Protecting yield potential:

By using advanced technologies to mitigate pests and disease losses, it is estimated that yield loss from genetic potential could be reduced by between 5-10%. Studying the causes of Septoria Leaf Blotch, Fusarium Ear Blight and 'Take-All', which have the largest detrimental effect to UK wheat yield, will reduce reliance on pesticides and add resilience and profit to our industry. In the UK an additional 1t/Ha of wheat is worth an estimated £318M to the industry.

Determining soil resource interactions

The interaction between soil and plant roots is complex. By understanding how the mechanisms of soil properties and root characteristics interact in regard to water uptake and nutrient acquisition, more efficient varieties of wheat could be developed capable of withstanding changes to our climate (drought and heat). Increased nutrient efficiencies will also have economic and environmental advantages.

Utilising a system's approach to crop improvement.

By using computer modelling to explore, under different physiological and environmental conditions, which varieties perform to their maximum genetic



potential, these traits through the wheat genome mapping programme could, in the future, be identified and used in conventional plant breeding.

Rothamsted is working with many other research organisations and studies including;

At a national level: Wheat Improvement Strategic Programme John Innes Centre NIABTAG (National Institute of Agricultural Botany) Universities at Bristol, Nottingham, Lancaster, Sussex and Exeter.

International partners include:

G20 Wheat Initiative Wheat Yield Consortium CIMMYT (International Wheat and Maize) CSIRO Canberra (Commonwealth Scientific and Industrial Research Organisation) EMBRAPA (Brazilian Cooperation of Agricultural Research) USDA (United States Department of Agriculture)



5.0. United Kingdom

So I began my study tour at Rothamsted to learn at first hand how their researches were going and I followed this up with visits to other leading UK research establishments with which Rothamsted also works.

5.1. Rothamsted

I met Professor Martin Parry (Head of Plant Science) and Dr. Malcolm Hawkesford (leader of the 20:20 Programme) and identified 4 main areas relevant to my study:

- 1 **Light capture**. As farmers we are turning sunlight into food. Plants need to maximise light interception for photosynthesis. Optimizing and maintaining the green leaf area for maximum photosynthesis is achieved with a combination of plant breeding (leaf and plant canopy structure), plant nutrient availability, and plant protection.
- 2 **Genetic potential**. Currently the yield gap between the Recommended List (RL) varieties and on-farm varieties is widening. We have the genetic potential to achieve higher yields, but on a field scale we are falling short and we need to understand why.
- Plant carbon dioxide efficiency. Increasing the rate of CO² absorption and its efficiency within the plant will result in more carbon being produced; leading to higher plant biomass and potentially more yield. Climate change will result in more CO² in the atmosphere so some yield improvement will come through this process anyway, but not at the required pace, estimated to be at 2% per annum.
- 4 **Soil and root interaction for nutrients and water**. Enabling roots to forage unrestrictedly will enable maximum uptake of water and nutrients. These are key aspects when developing yield. With 30% of UK wheat grown on drought-prone soils the average annual losses are between 1-2t/Ha.

I now moved on to one of their partners: the John Innes Centre at Norwich.

5.2. John Innes Centre

As part of the National Wheat Improvement Strategy Programme (WISP) - with teams working at the Universities of Bristol and Nottingham, Rothamsted and NIAB - Dr. Simon Griffiths is investigating and then mapping the genes involved in plant heading (seed head out) and plant height. Paragon spring wheat is being crossed with varieties from the Watkins Landrace collection. The collection, gathered in the 1930s by A.E Watkins, totals 1,150 different wheat varieties from all over the old colonial empire. By narrowing the varieties from the collection to 7, genetic variation shows different plant heights of between



55cm and 150cm, and ear emergence of between 77 and 109 days.

Identifying the genes that contribute to height and flowering times is very important. Even with climate change, one thing that will not change, around the world, is daylight hours. This in itself may not lead to higher yields but it could be used to increase the global area of land capable of growing wheat: e.g. short growing seasons in cooler climates. This technology could be used in countries with hotter climates to bring the grain fill period forward before late droughts. Getting crops to harvest earlier in the UK will help build resilience to our farming system, now wetter summers seem to be a more regular occurrence.

Next I visited the James Hutton Institute in Dundee.

5.3. James Hutton Institute

I met Professor Geoff Squire at the LEAF (Linking Environment and Farming) Innovation Centre where the Institute is working on three main areas that will be beneficial in increasing wheat yields:

- 1 The Sustainable Cropping system looking at a 6-year rotation comparing 'conventional' or 'best local practice' versus a system aimed at maintaining crop output with reduced input costs. Reduced costs include cultivations, fertiliser and pesticide applications. Comparable evidence is being gathered on many levels including field yields and quality, soil erosion, weed seed bank, nematode, water and small mammal movement.
- 2 Dr Alison Karley is working to identify root traits for better nitrogen use efficiency. In order to grow higher yields of wheat more nutrients will need to be utilised by the plants. In principle there are between 3,000-4,000Kg of unavailable nitrogen/Ha, held mainly in the soil's organic matter, which is not accessed by crop roots. Modern wheat varieties are fairly efficient at utilising artificially applied nitrogen but not at accessing the vast reserves of natural nitrogen that are potentially available.
- 3 The third area of interest was identifying wheat genes involved in the root penetration of compacted soils. Soil degradation and compacted soils are a big problem in the UK and plants with more robust roots will have greater access to water and nutrients.

Another "must see" on my list was the National Institute of Agricultural Botany – the Arable Group.



5.4. NIABTAG (National Institute of Agricultural Botany - The Arable Group)

I visited NIABTAG near Cambridge, and spent valuable time there with Bill Clarke (Commercial Technical Director) who gave me a great insight into their research. Their research extends to the recommended lists, innovation farms and extension work to farmer members. Membership income only makes up about 10% of their funding, with the balance being from commercial work or contract work from industry or the BBSRC (Biotechnology and Biological Science Research Council).

My visit coincided with the release of one of the latest advances in modern wheat breeding. The creation of synthetic wheat, which originated at CIMMYT (International Wheat and Maize Improvement Centre) in the 1980s, has now been developed at NIAB using wheat lines (varieties) in temperate, high output cropping systems for the first time. This process involves crossing durum pasta wheat with wild-goat grass using traditional crossing techniques in the glasshouse, combined with tissue culture in the laboratory, to guarantee seed germination. The resulting hybrid plants produce the synthetic seed, which is then used in crossing programmes with current varieties. Senior Plant Breeder Dr. Phil Howell says *"based on early-stage trials, yield increases of up to 30% have been produced"*.



Bill Clarke (Commercial Technical Director NIABTAG) with durum wheat and goat grass synthetic wheat

All plant breeding involves producing plants with new combinations of genes, but by using genetic modification the effect of individual genes changes can be seen, which is impossible using traditional methods.



5.5. Cranfield University

Professor Jane Rickson very kindly hosted Natasha King, Tom Sewell and me for a day to demonstrate the work Cranfield University is doing regarding soil management. We were introduced to Karl Ritz, Professor of Soil Biology, and throughout the day three key themes became clear:

- 1 **Soil structure** what makes up soil and what we do to impact on its ability to support and sustain the crops we grow.
- 2 **Soil biology** the prospect of planting mixed species in the same field, e.g. a mix of peas and oilseed rape or peas and oats, harvesting them together to sell as a blend or to separate in the grain store. This multi-crop option will encourage a more diverse population of soil microbes able to adapt to changing levels of crop residue, recycling nutrients at a faster rate and making them more available to the crop when needed.
- 3 **Soil behaviour** how soil particle size, field slope and cropping all contribute towards erosion issues. Whilst not directly related to growing a 20t crop of wheat, maintaining the valuable topsoil in the field is critical to reduce water pollution (mainly phosphate and pesticides) by keeping these nutrients in the field where we need them.



The trays above demonstrate how different soil types under cultivation behave in different rainfall events with different topography. The tray on the right shows the movement of soil down a 'tramline' being intercepted by a grass buffer strip. The velocity of the water flow is impacted by topography, crop residue or growing crop. When the water has reached a



certain velocity it moves down the slope taking soil particles (carrying pesticides and fertiliser) with it. The tray on the left shows where no compaction is evident, the soil remains in the field where it belongs. Rainfall creates micro compaction on the soil surface, creating a barrier to water infiltration and increasing runoff. Keeping the soil surface covered with catch crops or cover crops at all times will mitigate these erosion events; increase water infiltration and reduce runoff, ultimately reducing the diffuse pollution risk.

5.6. ADAS

ADAS is the UK's largest independent provider of environmental consultancy, rural development services and policy advice. I met Professor Roger Sylvester-Bradley at ADAS (Boxworth) in May 2013 and he really got me thinking about what is required to grow a 15T/Ha crop of wheat - let alone a 20T/Ha crop - with the current resources at our disposal. One of the main topics of discussion was the role of the canopy in capturing sunlight. Sunlight is crucial and a hot summer day (not over 28 degrees) can deliver 30MJ/m2 of energy, which can equate to 0.4T/Ha dry matter/day as long as water availability is not restricted. An average day produces 17MJ/m2 (0.22T/Ha DM) and a cloudy day, as recorded in the UK during the grain fill of harvest 2012, could only deliver 8MJ/Ha (0.1T/Ha/DM). Obviously we have no control over the levels and intensity of sunlight but the correct canopy structure will allow the wheat plants to compensate through the growing season.

Seed rates and planting date have a key role to play, with high yields being derived from wheat sown in August in the UK. The target is to establish 125 plants/m2 with enough tillers to achieve 500 ears/m2 at harvest. Grass weeds, especially blackgrass, will determine which fields are suitable for this very early planting. Early planting will enable the crop to develop more biomass or Green Area Index (GAI) above ground and more developed roots below ground. A greater GAI means the plant has grown more biomass and effectively stored more nitrogen from the soil, which is 100% efficient when used by the plant in the spring. This is very important when calculating the nitrogen fertiliser requirements for the crop in the spring. (Table 1). GAI reference photographs are shown in Appendix 5.

	8.4T/Ha	15T/Ha	20T/Ha
Crop GAI *	1.0	1.0	1.0
Soil Mineral N **	90	90	90
Soil Efficiency (medium soil)	60%	60%	60%
Target Yield T/Ha	8.4t/Ha	15t/Ha	20t/Ha
Target Protein %	11.0	11.0	11.0
Grain N Conversion	75%	75%	75%
Additional N Required	106Kg/Ha	347Kg/Ha	529Kg/Ha

Table 1: Manufactured N requirement to achieve target yield

* Assuming a GAI of 1 in February

** A Soil Mineral N of 90Kg/Ha as value in a typical cereal rotation after a legume/oilseed rape on a medium soil.



The rates of manufactured nitrogen to achieve these yields will be in excess of the RB209 guidelines for fertiliser application unless written documentation can justify the field total.

Phosphate and potash are two major nutrients that need to be available through the growth and grain development phase of the crop, in relatively large quantities (Appendix 6). The table below shows the offtakes in the grain of these nutrients only, but peak demand, especially of potash, during flowering means the plant will require well in excess of 400Kg/ha of potash.

	8.4T/Ha	15T/ha	20T/Ha
Phosphate P ₂ O ₅	65.5Kg/Ha	117Kg/Ha	156Kg/Ha
Potash K ₂ O	47Kg/Ha	84Kg/Ha	112Kg/Ha

Table 2: Phosphate and potash removal

The availability of nutrients from the soil is a complex one but Appendix 7 demonstrates the relationship between available and unavailable potassium in the soil.

5.7. United Kingdom summary

Firstly I have to say that I was encouraged by the detailed scientific research being undertaken by the institutions and individuals that I visited. I was also pleased at the level of cross-institute collaboration, not just nationally but on an international level. I am concerned with the reduction in Agricultural Research and Development funding (Appendix 8) and the apparent disbelief that food security will be a problem here in the UK. My conclusions from the work into increasing wheat yields in the UK can be summarised in the following three areas: Genetic improvement, Soil management and Crop nutrition.

Genetic improvement

The genetic research to map the wheat genome and to identify genes from older landraces¹ is very important work. Our current elite varieties of wheat have a fairly narrow gene pool, which is putting their disease resistance to the test. Widening the genes we use will have a positive effect on future plant breeding. Using gene markers to identify plant traits within the genes will also speed up and reduce the cost of plant breeding, bringing varieties to the market more quickly. Plant breeders must also look at disease resistance as part of the package and not just breed for yield. It is important for farmers to continue to buy certified seed and pay royalties on that seed so that plant breeders continue to invest, bringing new and improved varieties to the market in the future. The exciting work at NIAB Tag on the

¹ A landrace is a local variety of a domesticated plant species which has developed largely through adaptation to the natural and cultural environment in which it lives.



development of synthetic wheat should speed up the breeding and lower the cost of future genetic improvements.

Soil Management

For me, improved soil management is the key to increasing wheat yields. Our soils have been degraded over the years through intensive cultivations. Across a 15 year period from the mid-1980s soil carbon was being lost at a rate of 0.6%/year, equating to a 1% loss of organic matter. That 1% of organic matter would have had the ability to store 250 m³ of water/Ha, equivalent to 25mm of rain. Across Wales and England erosion moves 2.2 million tonnes of arable topsoil every year, equivalent to 12mm of topsoil lost per year, and deposits much of

Across Wales and England erosion moves 2.2 million tonnes of arable topsoil every year, equivalent to 12mm of topsoil lost per year and deposits much of this in our rivers and watercourses taking nutrients and pesticides with it.

this in our rivers and watercourses taking nutrients and pesticides with it. There are two elements of soil we need to focus on:

- Increasing the level of soil organic matter to at least 5%
- Improving the soil structure.

Nutrients

The tables above (in Section 5.6 on the previous 2 pages) demonstrate the level of the major nutrients that high yielding crops need to sustain growth and deliver yield. Those nutrients need to be delivered either from the soil or through the leaves. This requires very fertile sites or a high input of artificial fertilisers. Tissue testing is also required through the growing season to monitor any nutrient deficiencies before the symptoms are expressed in the crop, as yield penalties will already have occurred.

After these visits to the leading research centres in the UK – to thoroughly familiarise myself with the latest position re wheat growing research in our own country - I commenced my travels to Canada, USA, Mexico, New Zealand and Ireland, to look at leading practice overseas.



6.0. Canada

6.1. Alberta

I travelled with fellow Nuffield Farming Scholar Andrew Williamson for the first part of the Canadian visit. We flew to Calgary and after a day in the Rocky Mountains we headed off to visit an agronomy business called Agri-Trend. We visited Wheatland County, east of Calgary, which extends to about 40,000Ha and contains some of the best land in the state of Alberta. We met Robert Saik who founded Agri-Trend in 1997. His business model is very powerful and covers the main areas of crop agronomy (Agrology), soil mapping and variable rate technology (Geo-solutions), marketing and business management.



Left to right: Warren Bills, Andrew Williamson, Robert Saik, and Matt Gossling

The farm land in this part of Alberta has been in cultivation for about 100 years and has been zero tilled for the past 20 years. Through this latter practice the organic matter status and the workability of the land has increased dramatically. They grow spring wheat and have a maximum growing window of 120 days. This means that the operations have to be precise and efficient. The majority of the fertiliser is applied at the time of seeding and the

wheat will receive 2 fungicide applications: the first at growth stage 39 (flag leaf) and the second at growth stage 57 (start of flowering) to protect the ear from fusarium headblight, the main disease. No PGRs (plant growth regulators) are used on the crop which means nitrogen fertiliser rates must be carefully calculated to keep the crop standing. By limiting nitrogen application, the maximum yield is not

In Alberta ... crop development is rapid: for example, moving from Zadoks 30 (onset of stem extension) to Zadoks 40 (booting) in 10 days. In comparison a crop in the UK could take over 65 days.





High organic matter soil, good rooting and clean, disease-free stems and leaves of a spring wheat plant

reached but the crop remains standing! Plastic coated nitrogen (44.0.0) is used at seeding time and becomes available 30-40 days post planting as soil temperatures rise. This release is well timed as crop development is rapid: for example, moving from Zadoks 30 (onset of stem extension) to Zadoks 40 (booting) in 10 days. In comparison a crop in the UK could take over 65 days.

Sunshine hours and temperature accumulation are two major elements to maximising yield potential. In midsummer, sunset in northern Alberta can be 11.30pm and sunrise occurs at 2am. This advantage can be offset by limited rainfall (averaging 300mm) through the growing period and high temperatures. An average yield of spring wheat in Alberta would be between 75-80 Bushels/acre, which equates to 5 - 5.40T/Ha.

One of the main threats to the growing crop in Canada is frost as the crop ripens. Yields can be reduced by 50% if the crop is damaged prematurely by frost.

The picture above shows the high organic matter soils, good rooting and clean, disease free stems and leaves of a spring wheat plant.



Steve Laroque NSch and me



We headed north into the Badlands of Alberta where we met Steve Laroque, a 2008 Nuffield Farming Scholar, in his home town of Three Hills, an hour north east of Calgary. *(see picture on previous page)*. Steve runs a very successful agronomy business (Beyond Agronomy) in partnership with his wife Vanessa, walking 13,350Ha of crops, in addition to running his own farming business.

Steve is a big believer in 'Controlled traffic farming' (CTF) where all field operations take place along the same wheel tracks. I was very interested in the planting methods used for zero till so we headed to the local John Deere dealership, Evergreen's at Drumheller. In the yard was a Seed Hawk planter with both a seed hopper and fertiliser hopper with a capacity to carry 20T. Bearing in mind nearly all the fertiliser for the crop is applied at seeding; these rigs were huge, mainly pulled by tractors in excess of 500hp, either on duals, triples or tracks, with widths of up to 20m. Even transport widths were hovering around 5m. *See photo below.*

We also looked at the John Deere Conservapac opener which placed the fertiliser and the seed almost down the same drill row, seeding tine behind fertiliser tine, reducing soil disturbance, creating a very even drilling depth and capable of following uneven topography, with short leg length. Drilling speeds of around 4.5mph are common, so relatively slow compared to our drilling speeds but this reduces soil disturbance, which is key.



Seed Hawk planter with both a seed hopper and fertiliser hopper with a capacity to carry 20T.

Crop residue management is key to the success of this system. The previous crop residue (straw and chaff) needs to be evenly distributed and chopped by the combine. The residue mat keeps the soil cool, acting as an insulation layer in the summer. Soil temperature has a more positive effect on yield than air temperature as translocation from the roots is reduced, saving water for the vital 40 days of grain fill at the end of the growing season.

Breaking the wheat yield plateau in the UK ... by Jake Freestone A Nuffield Farming Scholarships Trust report ... generously sponsored by The Central Region Farmers Trust



Every day that crop senescence is delayed, a further 250Kg/Ha of yield is being accumulated. Insulation is not always ideal as the soil, covered in residue, is also slower to warm up in the early spring, potentially resulting in a delayed drilling date. This negative effect is offset by seedbed fertiliser (not widely practised in the UK) and by moisture conservation later in the season. Steve's crops would be grown on 300mm of rainfall in the year and, critically, 200mm during the growing season.



High organic matter soil from Three Hills, Alberta



Wheat planted between rows of canola stalks

The picture above shows wheat plants being planted between the rows of canola (oilseed rape) stalks. Using guidance on the tractors (RTK – Real Time Kinematics) the roots follow



the old crop root channels down, enabling faster root development. It also acts as protection to some degree to the young shoots as they emerge.

In summary the points taken from Alberta to raise wheat yields are:

- Zero till builds soil organic matter
- Residue management is key to the success of zero till
- Precision farming techniques such as CTF and field mapping enable better, more targeted use of crop inputs
- Moisture conservation is needed to maximise yield
- Timely crop establishment through seedbed fertiliser and suitable efficient farm machinery
- In a very short window of opportunity, timeliness is critical

6.2. Saskatchewan

Saskatchewan contains approximately 15 million Ha of cropped land, which is 41.7% of the total cultivated area of Canada. On its own it accounts for 10% of globally exported tonnes



Barbara Stefanyshyn-Cote NSch and her family

of wheat. With 90% of the crop planted in the spring, the same principles of wheat production are applied here as in Alberta.

I based my trip around the University of Saskatchewan and stayed with the Chair of Nuffield Canada, Barbara Stefanyshyn-Cote NSch and her family on their farm. I am very grateful indeed for the very kind hospitality from John and

Barb and their family during my stay in Saskatoon.

The University specialises in plant breeding and is located around Innovation Place, a Business Park for allied research companies and organisations. It was at Innovation Place I met Garth Patterson, head of the Western Grains Research Foundation (WGRF).



WGRF is a farmer funded and directed non-profit organisation investing in agricultural research that benefits western Canadian producers, funded through grower levies (wheat and barley variety development check-off fund) and an endowment fund, totalling \$7

million annually. WGRF identifies research projects which are then evaluated on the basis of science, impact and the probability of success with the final decision on whether to grant funding held in the hands of the 14-strong farmer board. The endowment fund allows for longer term projects that might not get commercial funding. The primary benefit of this shared research is in new varieties coming to the market place and information through winter grower meetings. New varieties are bred targeting increased yield, improved disease and insect resistance, developing special characteristics which enable them to adapt to the climate and improving overall quality.

I met Faouzi Bekkaoui, the Executive Director of the Canadian Wheat Improvement Flagship Program at the NRC (National Research Council).



Faouzi Bekkaoui, the Executive Director of the Canadian Wheat Improvement Flagship Program at the NRC (National Research Council).

The Canadian Wheat Improvement Flagship is NRC's

contribution to the Canadian Wheat Alliance (CWA), a strategic collaboration with Agriculture and AgriFood Canada (AAFC), the University of Saskatchewan's Crop Development Centre, and the province of Saskatchewan.

The CWA is currently focused on six projects that will reduce wheat losses due to drought, heat, cold stress and disease, and reduce nitrogen fertiliser requirements. They are as follows:

- **Genomics Assisted Breeding** (GAB) Using high throughput DNA sequencing and genotyping technologies to develop and deploy novel genomic tools.
- Wheat Improvement through Cell Technologies (WICT) Delivering methodology for low cost routine production of doubled haploids.
- Enhanced Fusarium and Rust Tolerance (EFRT) Developing durable genetic resistance against fusarium head blight (FHB) and rusts.
- Improving Wheat Productivity under Conditions of Abiotic Stress (Abiotic stress project) – Delivering markers to facilitate traditional breeding efforts, and identifying superior gene alleles that will serve as a genetic platform to pyramid multiple superior gene alleles into one cultivar.

continued on next page



- Targeting Developmental Pathways to improve Performance and Yield in Wheat (Development project) – Delivering a comprehensive gene expression atlas for wheat seed development; identifying genome-wide expression programs associated with maternal and/or paternal alleles during seed development; and developing a suite of potential gene targets associated with improved performance and seed yield traits.
- Beneficial Biotic Interations (BBI) Applying a powerful metagenomics platform to identify wheat microbe interactions that will reduce nitrogen requirements and define the microbiological characteristics of healthy productive soils for wheat varieties



With head of the Global Institute of Food Security (GIFS) Dr. Roger Beachy

The following day I had the great pleasure of meeting the head of the Global Institute of Food Security (GIFS) Dr. Roger Beachy, former Chief Scientist to the U.S. Department of Agriculture; appointed by Barack Obama, he has been in post since January 2013. I was very privileged to meet him and my half an hour slot soon became an hour as there was so much to discuss.

GIFS has been set up with funding from Potash Corporation of Saskatchewan Inc., (\$35 million) along with \$15 million from the Provincial Government of Saskatchewan, so has funding for 7 years. The purpose of GIFS is to bring three main streams of agriculture together to fund research and to have an overall agricultural strategy. GIFS's mandate is to 'Address the increasing global demand for safe, reliable food' The aims will be to help farmers cope with

climate change, when battling to improve productivity and maximise profit margins while balancing long term sustainability.

Roger is adamant that times are changing: food needs to be more nutritious, which can be achieved with the help of plant breeders. Together, plant breeders, farmers, scientists and marketers can develop, grow and then sell less, but higher nutritionally-valued food, with reduced environmental impact. This has to be the future and it's great to have that vision. He also commented that there are no short term fixes for long-term problems, referring to the issues of climate change and population growth. We touched on the issues of genetic modification (or 'Biotech' as we perhaps should be branding it now?); how biotech wheat can resist sprouting in the ear, increasing harvest yield and quality. However the customer has to want this technology and our customers are not hungry enough to accept these



technologies. Perhaps ask a farmer or a consumer in a developing country and you will get a different answer.

In summary the points taken from Saskatchewan to raise wheat yields are: -

- Farmer-led research has to be part of the solution
- Funding levels need to be increased in the UK with state funding
- Cross departmental/institute research to reduce costs and increase 'team science'
- Biotech solutions need to be available to the UK farmer

6.3. Summary from Canada

The key messages I will take away from Canada are: -

- The careful use of genetically engineered crops should be available to the UK farmer. A genetic solution becomes more important, as active ingredients are not being re-registered within the European Union and the UK for pest, weed and disease control.
- Zero tillage can work very successfully to increase soil organic matter, retain soil moisture, improve soil structure and increase yields.
- Seedbed fertiliser is key to getting short season crops (i.e. spring crops) off to the best possible start delivering their maximum yield potential.
- Precision farming techniques should be applied to maximise the return of crop inputs.



7.0. United States of America

7.1 Oklahoma

Oklahoma grows about 2.4M Ha of winter wheat every year, with the majority being hard red winter wheat for bread making which is exported from the great plains. Winter wheat also plays a significant role in cattle production with 'stocker' cattle grazing the crop until GS 30. (*See Appendix 10 which shows the Zadoks scale*). Depending on marketing conditions between 30-50% of wheat crops are grazed by cattle. A proportion of wheat is grazed right out if cattle prices are good or feed stocks are low. Average wheat yields in this area are between 1.5-2T/Ha with drought and over-grazing being the two main reasons for reduced yields. 2011 was a year of records in Oklahoma with new records set for cold, snow, drought, heat, tornadoes and hail. It reinforced the fact that our weather patterns are changing. In the summer period, evaporation can be as high as 20mm/day with at least 60 days over 100 degrees Fahrenheit and an average annual rainfall of 960mm.

I visited two main research stations looking at wheat production in the area. The first was the Samuel Roberts Noble Foundation based in Ardmore. Lloyd Noble set up an oil business in 1921 and quickly became very successful. His business had two main philosophies: hire the best people and use the latest technology. After witnessing the dust storms of the 1930s Lloyd commented:

"The land would need to produce our food, clothing and shelter long after the oil and gas has gone; and that years of man's failure to return anything to the soil had resulted in a barren, non-productive land that was susceptible to erosion and incapable of supporting a viable economy".

Water is certainly the most restricting limit to yield, and the soil is not dissimilar to the very light sand and gravel areas of the farm at home. Zero tillage is not practised by everyone in the area, with some farmers continuing to regularly cultivate the stubbles through the summer. The two photos below were taken on the same day on either side of a road, one farmer practising zero tillage (left) and the other full cultivation (right)





This farmer practised zero tillage

and this farmer practised full cultivation

Breaking the wheat yield plateau in the UK ... by Jake Freestone A Nuffield Farming Scholarships Trust report ... generously sponsored by The Central Region Farmers Trust



I couldn't scientifically measure the difference in the organic matter of the soil but it was obvious to see. The soil organic matter was holding noticeably more moisture, which would be available to the following crop. The residue was also acting as a mulch layer keeping the

soil surface cool and protected from the sunlight, reducing evaporation. This was enabling the grower to actually plant a second

I couldn't scientifically measure the difference in the organic matter of the soil but it was obvious to see. The soil organic matter was holding noticeably more moisture

summer crop after the wheat had been harvested, enabling more income to be generated from the land. In order to speed up the process of harvesting and planting, stripper headers were being used. This enabled the stubble to remain tall, shading the soil surface and emerging seedlings from the sun. The shading and cooler soil surface temperatures also



stubbles previously harvested with a stripper header meant that a greater percentage of rainfall would penetrate the soil.

This photograph shows а recently harvested (with а stripper header), wheat field and bean plants emerging soya between the rows. The wheat was sown in 25cm rows using automatic tractor steering and the soya is sown between those rows using the same precision guidance technology.

Wheat stubble

Corn crop residue (previous year)

Soya bean plant

wheat





With Jim Johnson Jr (right - Soil and Crops specialist)

Further research being initiated by the Foundation, led by Jim Johnson Jr. (Soil and Crops Specialist - right) is into the use of cover crops to build organic matter levels in the soil. There is a lot of scepticism about how much moisture the cover crop will take away from the soil, which therefore won't be available

for the following wheat crop but in reality this doesn't seem to create too much of a problem.

71% of the growers present were entirely zero tilling.

The interest is gaining momentum and I was lucky to be invited to an extension meeting, led by Jim at the Stuart Ranch, while on the

way to my next meeting. Of the farmers and ranchers who were present only 5% used cover crops on every acre every year and, of those, 22% said that improved soil health resulted from doing so. 71% of the growers present were entirely zero tilling.



Species trialled include (left to right) grazing corn, pearl millet, brown top millet, brassicas, cow peas and sunflowers.

Some cover crop experiments are looking at different species to perform unique functions in the soil. These functions include compaction removal, nutrient scavenging, soil stability (reduced wind erosion), increased soil health (microbes and fungi) and organic matter build up. Species trialled include (left to right) grazing corn, pearl millet, brown top millet, brassicas, cow peas and sunflowers. The trend of using cover crops for all the soil benefits





Jimmy and Margaret Anne Kinder

described above, is very new in Oklahoma - and also in the UK - and more research needs to be undertaken to really understand the benefits to the soil health.

I spent the weekend with Jimmy and Margaret Anne Kinder on their farm in Cotton County Oklahoma. Jimmy farms about 5,000 acres of cash cropping (wheat and canola) as well as running stocker cattle through the winter period

on the wheat fields. The farm is near the town of Walters, south west of Oklahoma City near the Texas border and is in a very dry part of the world averaging about 810mm/year (32 inches). Jimmy is a very progressive farmer and has been using zero till on his soils for almost 20 years and was one of the first in the county to use this technique. Working with Oklahoma State University, Jimmy has been trialling the use of the GreenSeeker² to aid nitrogen application rates on his wheat fields. The GreenSeeker measures the plant biomass and, with this knowledge, a fertiliser rate can be applied to the field, rather than using previous standard fertiliser rates. This enables a more targeted approach to prevent wasting an expensive crop input in some areas of the world where a harvest is not guaranteed.

Jimmy and Margaret Anne looked after me with great generosity, taking me on a tour to Mt Scott in the Wichita Mountains and to a local wildlife reserve where I came face to face with a herd of bison. We visited Fort Sill on the way home and stopped off at a burger and icecream chain called 'Braums', now a national chain which was started by Henry Braum. On Sunday at the Church of the Nazarene in Walters, I was touched by Edward Eschiti, who



Havoc left by recent tornado

sang a song for me in Commanche (Native American Indian).

I headed north to Stillwater, calling in at the town of Moore where just over a month earlier a tornado touched down. It was on the ground for 39 minutes and tracked for 17 miles with top wind speeds of 210mph. The tornado tragically killed 24

² Trimble's GreenSeeker system uses optical sensors to measure and quantify the variability of the crop. It then creates a targeted prescription to treat the crop variability



people. It was a very sobering sight driving through the suburban area in such eerie silence. The resilience of the residents was good to see and although many homes were under-



Jason Warren, Assistant Professor, Soil and Water Conservation/Management Extension Specialist standing in front of cover crop trials

insured there were adverts on the radio encouraging people to donate much needed funds to the stricken families.

My meetings at Oklahoma State University were kindly organised by Jason Warren, Assistant Professor, Soil and Water Conservation/Management Extension Specialist, who took me around the University Research stations. One of the key messages Jason and the team are trying to get across to the farmers is the benefit of cover crops and rotation in lifting overall yield. Genetically modified

canola is the latest alternative to wheat to be grown in the area. From 2007 to harvest 2012 the area of canola (oilseed rape) has gone from zero to 81,000 Ha and after 3 consecutive cotton crop failures even more interest has been generated. Farmers are also scouting their crops regularly and targeting inputs for better return on investment, as Jimmy Kinder demonstrated with the GreenSeeker.

With low humidity, high temperatures and strong winds these fields can lose over 530mm of moisture over the summer period. Cover crops would use up a proportion of this moisture,

but that moisture would disappear anyway. By using cover crops, nutrients are being retained in the organic matter to be made available later in the plant cycle when cover crops decay. Soil organic matter in the region is between 0.75% and 2% and, with a wheat crop at full canopy using 6mm of water/day in respiration, increasing the OM in the soil will have a direct impact on yield. Importing sources of OM is not feasible as the area of crop is

One of the key messages Jason and the team are trying to get across to the farmers is the benefit of cover crops and rotation in lifting overall yield.

too large, so the only method of increasing OM is to leave the previous crop residue and grow cover crops.

The picture above is of Jason at Lahoma, one of the experimental farms, standing in front of the cover crop trials. The idea was to look at different mixes of cover crops, singly or in mixes, as a demonstration for local farmer open days. The plots were made up of sunhemp, cow peas, millet and sorghum. The post harvest yield data is shown in Appendix 9 with no



statistical difference in increase or reduction of the wheat following cover crops. (*Prof. Warren*).



Matt Alig

There are farmers and ranchers who have taken up the cover cropping idea and are making a success of it. One grower is Matt Alig, shown here (above) in his sorghum, sudan grass and

cow peas mix (a row of each planted with a John Deere air seeder). The tall stubble which is protecting the crop from wind (evapotranspiration) is the grazed remains of forage rye and triticale used to fatten 'stocker' cattle over the winter. Incidentally Matt manages to stock at twice the density of others, due to cover cropping. Matt puts this down to extra moisture retention at planting (August) due to the amount of organic matter covering the soil. When 100mm of rain falls in an afternoon it is important that it goes through the soil profile and

Matt manages to stock ("stocker cattle") at twice the density of others, due to cover cropping. Matt puts this down to extra moisture retention at planting ... due to the amount of organic matter covering the soil.

is protected without washing off or being blown away from bare soil.





Robert Blair with UAV

7.2 Idaho

Idaho sits in the region of the Pacific Northwest (PNW) with Washington and Oregon states. Wheat forms part of a much wider rotation here, along with barley, oilseed rape, peas and beans. Different types of wheat are grown, from soft white wheat for biscuits, hard red wheat for bread making, hard white wheat for noodles, and durum wheat for pasta production. Wheat yields average 85 bu/acre or 5.8T/Ha - in a climate very similar to that of the United Kingdom. Kendrick County, where I stayed with Robert, Rhonda, Dillon and Logan Blair has an average annual rainfall of 680mm. Robert is an Eisenhower Fellow and has been involved in the use of Unmanned Aerial Vehicles (UAVs or drones) for crop scouting since 1996.

The family farm is called 'Three Canyon Farms' and is typical of the geographical location, with steep sided canyons and productive land on the plateaus between. Robert jokes, "It's one of the few places on Earth where we farm 3 sides of an acre, due to the steepness of the canyon sides".

Robert regularly flies his UAVs to assess the variation of crop growth relating to field and soil variability. He is then able to download the information from these photographs and, through software he has developed, create variable application plans for nutrients. Robert has also used these maps to examine crop loss claims for wildlife damage as areas of crop



Imagery collected via UAV

loss can be easily spotted from above. An example of the imagery collected is seen to the left.

Robert is keen on this technology as the UAV flies autonomously and can travel under cloud cover, which has advantages over satellite imagery as you can fly it where and when you want or need to. This type of imagery can also pick up different crop issues from compaction, weed identification and different crop biomass. The use of application technology is something that we have to make more use of to optimise our crop inputs. By identifying the 'limiting factor' in the field through remote scanning, (in the case of the UK, its water-holding capacity) we

should be able to invest more inputs into these areas to maximise the crop yield.

Robert had very kindly organised a couple of visits for me in Washington State. We met Jean-Bruno Beaufume, who works for Limagrain Cereal Seeds as a wheat breeder. Limagrain originated in France as a farmer-owned co-op to start developing newer, more productive seed varieties. In the US they are the 3rd largest breeder behind Monsanto and



Pioneer and specialise in field crops such as wheat, barley, canola and sunflowers. Limagrain have a knowledge-sharing agreement with the University of Idaho enabling them access to 25-27 wheat breeding programs. As the climate is very similar to northern Europe many varieties from there are being investigated to see if they can bring genetic variation to the Pacific North West varieties. The trial network that Jean-Bruno looks after at Walla Walla covers 30 acres with over 16,000 research plots and 1 million plants that will have ears harvested from them.

We discussed the yield plateau issue, which is not just a UK phenomenon, and came up with 4 main reasons:-

- Climate is a big challenge, especially heat stress. Fluctuating temperatures and drought, either short or long term, are causing yield reductions.
- Economics and politics; namely the cost of nitrogen fertiliser and the environmental restrictions to the amount that can be applied.
- Grower prioritisation of inputs; i.e. spending more money on conserving yield through weed control and fungicides rather than spending on fertiliser and trace elements to increase yield.
- The underfunding of research by breeding companies. If you compare wheat historical yields to those of corn you can clearly see the benefit of increased funding. The graph below clearly demonstrates this point and shows the widening of the yield gap between corn and wheat since the major impact of genetically modified corn.





As 80% of the soft white wheat varieties are exported to Japan and Korea for noodles and cookies (similar to our group 3) plant breeders in the PNW are focusing on yield increase, resistance to stripe rust, stem based disease and end use quality. Other areas of stabilising crop yield that are being investigated are: tillering ability, head fertility and specific weight (thousand grain weight). It has also been noted that when legume crops are removed from the rotation a drop in yield usually occurs.



Contour farming to reduce soil erosion showing fallow, wheat and peas

On the way back to Kendrick we called in at Bill Warren's farm (Dayton WA) near the old Green Giant canning factory. Bill is an Eisenhower Fellow and farms some incredibly steep land. The field working machinery is on tracks, including the sprayer, and the land is contour-farmed to try and reduce soil erosion with different crops harvested and fields



Dwayne Beck at Dakota Lakes Research Farm

worked at different times. The hill above shows fallow, wheat and peas contour farmed in this way.

7.3 South Dakota

I met Tom Sewell, fellow UK Nuffield Farming Scholar 2013, at Pierre and headed out to visit Dwayne Beck at the Dakota Lakes Research Farm (left). The research farm's goal is to identify, research, and demonstrate methods of strengthening and stabilising the agriculture economy. The research farm has about 480mm of rain per year with 1/3 of that coming in the form of snow. Moisture capture and conservation are key reasons for the no-till system. No cultivation, other than

seeding, means the macro-pores the 'night crawlers' (worms) create are not disturbed, so drainage into the soil profile is fast and efficient when it actually




Zero tilled soya beans planted into heavy corn residue

rains. The water seeps down these tubes in the soil until they find a dry area and then move outwards soaking the soil at depth, rather than surface run off. These worm channels also enable the worms to migrate to the surface to collect crop residue and digest it in the soil. This process enables roots to follow the worm channels, accessing water and recycled nutrients as they grow down. The infiltration rate is easily demonstrated when 37.5mm of rain is applied through

irrigation in 6 minutes and shortly afterwards you can walk on the field in your slippers! Cover crops, especially linseed (flax) also play a role in providing little snow fences stopping snow blow across the Northern Great Plains during the winter.

Crop residue plays a vital role in recirculating the soil nutrients, keeping the soil cool and damp by protecting the surface from wind erosion. The previous crop residue will disappear in a relatively short space of time. Wind erosion issues such as the mid-west dust bowls of the 1930s have created many problems for the area in the past but now, with this method of crop establishment, yields are increasing, the environment is improving and farmers are actually making money.

Dwayne also stressed the benefit of rotation to change the nutrient recycling speed of different crop residues. A rotation of corn, corn, broad leaf (peas, beans), wheat, cover crops (foxtail, millet and oats), soya beans and then back to corn is one rotation being trialled at the research station to bring diversity into the farming system.

We also talked about fertiliser being placed with the seed at planting, a similar strategy to those I saw in Canada. Placing the fertiliser near the seed means that it is readily available when the plant needs it and it's also away from germinating weeds on the surface. Quick emergence in a short season (due to drought) and having nutrients available, means plants get to the maximum light interception earlier, increasing capture of sunlight and with enough moisture can generate the most yield.

The picture on the left on next page, page 32, is of a 2nd corn crop direct drilled into the previous stubble and crop residue. The planter used coped with the residue very well and the block looked stunning.

The picture on the right on next page, page 32, is of nodulation on a soya bean plant. Being leguminous it was fixing its own atmospheric nitrogen in a symbiotic relationship with soil bacteria.





Corn crop drilled into the previous stubble and crop residue



Nodulation on a soya bean plant

7.4 North Dakota

North Dakota, whose state motto is "Strength from soil", grows a wide range of combinable crops including 50% of all the spring wheat, 56% of all the durum wheat, 95% of all the flax



Beef cows graze each grassland area once per season

(linseed) and 90% of all the canola in the United States. North Dakota suffered, as many of the mid west prairie states did, with wind erosion in the mid 1930s, which ruined many farming businesses and forced communities to give up a rural way of life. This started to change from the mid 1970s when zero tillage began to improve the soil structure.

'Farming holistically with nature' and

'mimicking the natural methods used by mother nature to produce density rich quality food' were some of the first words that Gabe Brown said to Tom and me when we visited Brown's Ranch. Gabe farms 5,000 acres with his wife and son Paul, and some occasional hired help. The system is split into two main areas: cropping on outlying fields where there is no water, and high intensity short periods of grazing on permanent but improved grasslands.

Groups of cows are moved twice a day grazing the nutrient and carbohydrate rich seed heads and trample the rest of the plant (leaves and stems) back into the soil. This is not wasted but consumed by the billions of mycorrhizal and soil bacteria that feed on this carbon source. It is a great system that complements cow and calf production, allowing the stock to be kept outside for most of the year and only needing supplementary hay Gabe has not used inorganic fertiliser, insecticides or fungicides for 10 years and rarely uses herbicides.

feeding for 90 days. The grass gets grazed once a season, with no artificial fertiliser being





applied, mimicking the grazing patterns of the migrating bison. A herd of 400 cows range these pastures and all the beef is finished from grass into a premium market.

Gabe took Tom and me to visit a couple of his neighbours' fields by way of a comparison in soil health and structure. We looked at soils that just grew spring wheat one year and flax (linseed) the next; they had no soil structure or worms present. Soil with a little more structure was in a corn, spring barley, sunflower rotation all with zero tillage. Then we moved back onto Gabe's soils which, under his management of zero tillage, diverse rotation, cover crops and livestock were incredible. Gabe has not used inorganic fertiliser, insecticides or fungicides for 10 years and rarely uses herbicides.

Gabe's soil

The soil fractured so well, was alive with

roots, and smelt almost sweet. It really was a terrific visit, standing in a winter triticale field with grasshoppers leaping everywhere. There is very little cost to this farming system, which Gabe developed after 4 years of drought in the 1990s, when he had no crops to sell and therefore little money to invest.

The key to farming in this area of the US is making the most of the available water. With 400mm of rainfall per annum and 225mm of that coming in the form of snow melt, capturing that moisture is the key to success. Measured infiltration rates went from 12mm/hr in 1993 to 200mm/hr in 2013, due to zero tillage plus increasing the root content of the soil. Increasing root mass means extra drainage channels when the roots die, allowing much faster water retention in the field. This also improved water quality by reducing surface runoff.

Gabe is looking at the whole farming system rather than just individual crop performance. It almost doesn't matter what the crop yields as long as it is sustainable (economically, environmentally and socially). However, good yields on areas of the farm mean that not every acre needs to be selling a cash crop every year. Last year Gabe's corn averaged 127 bushels/acre in comparison to the county average of 100 bushes/acre and, with total costs of \$1.44 and a corn price of \$7, it's not hard to make some money in part of the rotation.



Diverse cover crops are also part of the equation to increase the soil health and biological activity.

Some mixtures contain 12-25 species to maintain biodiversity within the soil. These cover crops will have different effects on nutrient availability. For instance radish and turnip have low carbon content and will guickly release locked up nitrogen, whereas rye is high carbon and will release its nitrogen over a longer period. Having a balance means just that, a balanced healthy nutrient available soil.



Some mixtures contain 12-25 species



We met up with Jay Fuhrer (photo left), the County NRCS (National Resource Conservation Services) advisor, funded through the USDA (United Department States of Agriculture). Jay also manages the Menoken Demonstration Farm. In Native American, Menoken means, "You reap what you sow".

At the office we performed an infiltration and slake test on two soils.

The picture on the left (*see next page*) is soil from Gabe's farm and demonstrates the positive aspects of his soil. The jar on the left shows how the soil binds together with glomalin (glycoprotein), which is produced abundantly on hyphae and spores of mycorrhizal fungi in soil and in roots. Even in saturation soil structure remains intact stabilising the soil during periods of heavy rainfall.

The jar on the right has had the soil dried out and then crumbled a little before being put into the large plastic jar. The water is then poured into the top pot with holes in (mimicking rainfall) and drains through the soil profile and out of the bottom into the silver tray. Gabe's soils passed this water in a minute or so showing fantastic infiltration, which is just what you need during periods of high intensity rainfall.





The soil on the right took almost 10 minutes to start to drip. Had this been on a slope the soil erosion would have been incredible, taking soil and attached pesticides and fertilisers into the nearest watercourse.

The reason for this is due to soil structure and the airspaces within the soil. The spaces between the soil particles allow water to pass safely through. The water did run through the soil but due to the way the nitrogen is stored in the soil (bonded to the humus) only a small percentage was leached. In fact the poor soil leached twice as much nitrate. The slake test also clearly demonstrated the ability of Gabe's soil to stick together. This is due to the root exudates, simple sugars given off by roots, binding the soil together and making it more stable and able to withstand traffic and heavy rainfall.

In order to keep the soil healthy it needs to be fed carbon and protein which are delivered in Jay's rotation by growing cover crops. The one shown below contains: peas, oats, phacelia, wheat, radish, canola, turnips and clover.



Cover crop containing peas, oats, phacelia, wheat, radish, canola, turnips and clover



The insect life it was supporting was incredible; honey bees were everywhere. This cool season cover crop is grown just through the early part of the summer but it would be great to try this at home after harvest and before a spring crop. All these roots are releasing sugars, moving nutrients around and making locked up nutrients available to the plants.

Another interesting idea was a type of companion cropping. In the picture below, the cash crop of sunflowers is planted at 75cm intervals and inter-seeded with a cover crop.



Sunflowers, the cash crop, inter-seeded with a cover crop

This broadleaved cover crop contained buckwheat, flax, soybeans, cow peas, peas, radish and turnip. The idea was that the cover crop would grow alongside the main 'cash crop' and the cover crop would provide the nutrients required. For instance, the buckwheat would release phosphate from the soil and the legumes would provide a proportion of the nitrogen required.

... it is thought that, in a commercial scenario, fertilisers could be reduced by 50%.

This is an experimental farm so no extra inorganic fertiliser is applied but it is thought that, in a commercial scenario, fertilisers could be reduced by 50%.



7.5 Summary from United States

In summary the lessons I picked up from my travels in the United States, across some very different soil types and farming systems, are:

- Zero tillage needs to be experimented with and promoted more in the United Kingdom
- Multiple species within cover crops, planted simultaneously, will lead to increased soil health, soil structure and resilience in any farming system and can achieve multiple effects on the soil depending on the mixture
- Livestock integration into an arable system will add benefits to soil health and potentially enable higher rotational margins
- Precision farming needs to be used to target inputs for optimum return and to reduce environmental impact
- Genetically modified crops should be available in the United Kingdom to help offer solutions to plateauing wheat yields, nitrogen and water use efficiency
- Underinvestment in wheat breeding should be reversed and growers should continue to pay seed royalties to maintain a profitable wheat breeding industry, bringing a constant stream of enhanced genetics to the market place

8.0. Mexico

8.1 Obregon

"If the naysayers do manage to stop agricultural biotechnology, they might actually precipitate the famines and the crisis of global biodiversity they have been predicting for nearly 40 years."



Andrew Williamson (UK Nuffield Farming Scholar 2013) and I met up with Natasha King (New Zealand Nuffield Farming Scholar 2013) at the CIMMYT (International Maize and Wheat Improvement Centre) research station at Obregon in Senora, Mexico for the final leg of my North American journey.

The two Mexican research centres at Obregon and El Baton are run by CIMMYT, the home of the 'Green Revolution' where Dr Norman Borlaug changed the face of wheat breeding in the 1950s by breeding a dwarf gene into Mexican wheat varieties (which had previously been very prone to lodging because of their height). This dwarfing meant that more fertiliser could be applied to the crops, effectively doubling the yield. Borlaug and his team developed a unique plant breeding system between Obregon (Senora) and El Baton (Mexico City) and, by using spring wheat varieties, were able to generate two plant breeding cycles per year, in two different latitudes, which had never been done or thought possible before. By default the sites were very different; Obregon is 39m above sea level and is dry and arid, but with irrigation, whereas El Baton is 2249m above sea level, in a cooler more temperate climate. As a result of the breeding programme Borlaug's wheat varieties were high yielding, short, stiff-strawed and disease resistant (mainly to rust). By 1956 Borlaug had developed 40 new rust-resistant, high yielding, taller varieties that made Mexico self sufficient in wheat.

The new wheat varieties bred in Mexico were soon being trialled in India and Pakistan and, by 1968, Pakistan became self-sufficient in wheat and by 1974 India was self-sufficient in cereal grains. The green revolution had begun with high genetic potential, short straw, a



strong responsiveness and high efficiency to nitrogen applications and a broad spectrum of disease resistance.

"This new revolution can be as significant and as beneficial to mankind as the industrial revolution of a century and a half ago" – William S Gaud, Director, United States Agency for International Development

Our first visit was to Maria Elena Cardenas, who specialises in crop nutrition. In conjunction with OSU (Oklahoma State University) the team here developed the first greenseeker device for measuring the crop biomass (NDVI - Normalised Difference Vegetative Index), as trialled and used by Jimmy Kinder in Oklahoma. From this measurement an algorithm is calculated to give a fertiliser rate, which the farmer can apply to the field. Fertiliser and water quality are huge issues in Sonora, with water for crops being used from a series of wells and one major (Alvaro) Dam. Pictured (left to right) is Maria's team, Jose Cynthia, Marisol, Maria,



Maria's team, Jose, Cynthia, Marisol, Maria, Lorena and Alberto

Lorena and Alberto. They are currently working on a similar project to the greenseeker but measuring the levels of phosphate in the plants to give fertiliser requirements.

The team is also investigating handheld thermal imaging techniques to monitor stress levels within the canopy, through heat detection. As temperature rises the stomata in the plant shut down, resulting in



Matthew Reynolds (centre) a senior plant physiologist

an increased canopy temperature. This tool can then be used to regulate irrigation schedules to reduce and target the amount of water applied to the crop.

We met Manuel R. Velenzuela from PIEAES (Patronato para la Investigación y Experimentación Agricola del Estado de

Sonora), a farmers' research organisation, located at the Obregon site. Manuel gave a really great insight into the issues affecting the farmers of the Sonora area and specifically in the Yaqui Valley. Water is a crucial issue with crops having to be irrigated from either wells (down to 250m), or from the Alvaro Dam. Much of the wheat grown here is durum wheat

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and is exported through Africa into Europe. Average yields of 7.2t/Ha were recorded last year although the general average would be about 6.8T/Ha.

We met Matthew Reynolds (centre in photo on left) a senior plant physiologist who showed us around the farm and the work he's doing with the current breeding program.

Matthew reminded us that farmers are currently only reaching 50% of the current genetic potential of existing cultivars, partly due to water availability, funding for increased inputs, and the latest growing techniques. He also reinforced their breeding strategy: that no variety leaves CIMMYT without full resistance to rust diseases, as no fungicides are used in the developing world. To me that makes a lot of sense in the UK too, as resistance to fungicides and the potential withdrawal by the European Union of certain chemical groups will make disease control harder in the future. Plant sensing is being pursued at great pace to investigate drought tolerance through canopy temperature regulation, leaf water content, and rooting capability.

The soil in Obregon has very low organic matter, so where possible cover crops are being grown. Here Rodrego (farm manager, centre right in picture below) was showing us a field planted with sesbania. This is a legume that will grow to 2m tall in 12 weeks, with great nodulation and a fantastic tap root. These crops were only 4 weeks old and had already grown to about 50cm. The crop will be flailed off later in the season and spring wheat will be planted into the residue. Although the variety will be a spring wheat it will be planted in the winter period and will grow for just 5 months, from the middle of November. The crop may have 3-4 passes with the irrigator, each time delivering between 80-100mm of water.



Rodrego (farm manager, centre right) was showing us a field planted with sesbania.

After the experiences of cover crops in the United States I was pleased to see yet more evidence of this technique being used to improve soil organic matter content and increase soil fertility.

8.2. El Baton

Dr David Bonnet has been working at CIMMYT for the past 5 years as senior scientist on the Global Wheat Program looking at wheat breeding. We talked about the aims of the



organisation: to increase food security by increasing farmers' efficiency and keeping food affordable to people living in the cities. To me the two go hand in hand. If the farmers are more efficient and produce more food their income will remain viable and it will increase the supply of food therefore reducing the cost. It was also interesting to hear David's thoughts, that by increasing productivity in the developed world, it will help the developing world by creating a surplus of food, therefore lowering the cost of imports.

Hybridisation of wheat was mentioned as a way of increasing production, although very hard to achieve as the male and female parts of the wheat plants are close together. Half

the wheat varieties in the developing world come from CIMMYT and a further 25% have CIMMYT varieties in their parentage - which shows the importance of this organisation. It was worrying to hear that there are more dollars spent in one week on maize research by one particular company than the global research on wheat in a year.

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The double cropping, i.e. planting and harvesting in

Obregon and then moving the seed to El Baton, doubles up the genetic selections of these spring wheats. Effectively two crops are grown in every year. The plants have 2 years of selection this way before being sent to over 200 research centres around the world to make sure they are suitable in other climates, before returning to El Baton for the final selection. It is a fascinating process. Obregon is also able to simulate many different climatic conditions - drought, heat stress and irrigation - which means they can obtain the best genetic potential. There are between 1.5 and 2.5 million individual plants in the first year of selection, which are reduced to 500 over 5 years. The picture (below left) demonstrates the ability of Obregon to simulate drought verses irrigation trials and the picturce (right) indicates different disease pressures at various trial sites in Mexico.



Above left demonstrates the ability of Obregon to simulate drought verses irrigation trials and the picturce (right) indicates different disease pressures at various trial sites in Mexico.





Wheat ear in the breeding programme at CIMMYT

Enrique Autrigue showed us a presentation on the challenges we face as farmers and breeders over the next few years. By 2050 wheat yields must increase by 70% across the world, which means we need to take average world wheat yield from 3T/Ha to 5T/ha. Enrique estimates that 50% of this yield increase will come from plant breeding and 50% will need to come from crop husbandry. We also discussed the chromosomes that the wheat plants have and how they were formed many years ago from natural crosses of grasses. We talked about the major elements that all CIMMYT wheat varieties need to have in them, namely high and stable yield, durable resistance to rusts (UG99 is an aggressive strain), water use efficiency, drought tolerance, heat tolerance and end use quality. One fact that stood out was water use efficiency (WUE). Irrigated wheat in northern India with

flood irrigation needs 1300L of water for every 1Kg of wheat grown. With new technologies in drip irrigation this can be reduced to 500L/Kg. This will be essential to raise world yields.

Dr Masahiro Kishii talked about wheat cryogenics. This is basically crossing wheat with other grass types to show genetic differences. It is these differences that the geneticists are looking for to see if they will throw up new and exciting traits. Masahiro is looking at ancestral wheat (old cultivars - similar to modern wheat), alien species (translocation in from other types further removed from wheat) and even crossing wheat and maize to see what appears. A good example would be crossing grass species living on sand dunes near the sea. They would be tolerant to salinity and have good drought resistance but poor yield. Dr Kishii's research would answer whether these genes can be selected and bred into modern wheat to provide a higher yielding variety that is more drought tolerant than the varieties currently used.

Finally we met Thomas Payne (right), Head of the Wheat Germplasm Bank, where all the previous varieties of wheat and maize are stored. The store



Thomas Payne, Head of the Wheat Germplasm Bank

also includes wild varieties that are being stored to potentially extract the germplasm (genetics) later to see if they can help with a future problem. There are 144,000 varieties

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stored here and of these, 50% have undiscovered germplasm. The vault was at about zero degrees C but, downstairs at the lab, the deep freeze is at -18° C and it's used for long term storage of germplasm. It is estimated that varieties of wheat here will remain in viable storage for 100 years at least. This shows the need for organisations to work together and also to be in it for the long term.

8.3 Summary from Mexico

In Mexico the enthusiasm and passion for science and the quest to find better, more efficient, more disease tolerant wheat cultivars to feed the developing world were inspirational and that goal was shared by everyone involved.

The innovation and research ideas were very positive and included practical achievements, like the greenseeker, that had actually made it into the commercial world. The gap between the science laboratory and the farming community was smaller in Mexico than in other countries I had visited.

The vision that Dr. Norman Borlaug had for the shuttle breeding program, that is still at the heart of CIMMYT's breeding strategy, continues to amaze me. The impact that these varieties have had on world food production is phenomenal.

As reported in Science magazine, (Science 2 - 2003) in the absence of CGIAR (Consultative Group on International Agricultural Research) centers such as CIMMYT, with their many partners in the developing world:

- Crop yields in developing countries would have been 20-24% lower
- Prices for food crops would have been 35-66% higher
- Imports would be 27-30% higher
- Calorie intake would have been 13-14% lower
- 32-42 million more children would have been malnourished
- The area planted to crops would need to be 4% higher for wheat and 2% for maize to maintain current production



9.0. New Zealand

I visited New Zealand to explore the techniques used to achieve the highest recorded official wheat growing record in the world. I met both the current world wheat yielding record holder and the previous holder of this prestigious and sought-after record. Along the way I met some potentially record-breaking candidates who are growing very high yielding wheat crops. Every one of them was passionate about agriculture. They are farming in the relative freedom New Zealand offers for farmers to make cropping and business decisions in an unsubsidised, market led industry.

New Zealand grows approximately 1 million tonnes of grain/year consisting of wheat, barley and maize, almost exclusively for their domestic market. The average wheat harvest (2004-2013) totalled 368,000MT or 7.88T/Ha (*Mundi Index*). 70% of the wheat grown is varieties of feed wheat, for biscuit or animal feed markets. The highest area of wheat production is centred around the Canterbury Plains area in the South Island, near Christchurch.



Map of New Zealand

9.1 Cultivations

My interest in cultivations and direct drilling had certainly increased after the previous Nuffield Farming study tour to North America and so I was very interested to meet up with John Baker and the team at Cross Slot who have spent the last 30 years developing a complete, minimal-disturbance direct drill. I wanted to see this in action and to talk to growers who have used this system on different soil types and with different crops.



Meeting John Baker and Bill Richie, the designing team behind Cross Slot, was a great pleasure and has helped me in developing the system at home with extended trials. The concept is a simple one that encompasses many of the soil improvement strategies I have learnt about on my study tour and, with limited soil disturbance through direct drilling, the benfits will be:-

- increased soil organic matter which will enable the soil to have a greater water and nutrient holding capacity
- minimising the amount of soil mineralisation (carbon release)
- enables better field drainage by not distrurbing natural worm and root drainage channels, and allowing natural restructuring
- lower the chances of soil erosion through wind and rain by stabilising the soil surface and maintaining crop residue on the soil surface
- lowers the carbon emissions, cost and establishment time of arable crops

By nurturing the soil into a more resilient condition there is a much greater chance of optimising the genetic potential of the cultivars, as more nutrients can be held in the soil humus, and so are more readily available when the plants demand them. It is often said that we cultivate for the benefit of the drill, not for the benefit of the soil. It is my belief that soil needs to be covered at all times by residue or by a growing crop and this type of drill allows the following crop to be established into high levels of crop residue, without the need for any preceeding cultivations.

It is my belief that soil needs to be covered at all times by residue or by a growing crop and this type of drill allows the following crop to be estabished into high levels of crop residue, without the need for any preceeding cultivations.

One of the key lessons I picked up from the farmers using any direct drill is the need for seedbed fertiliser to get the plants off to the best start, especially in the spring. Increased soil organic matter means the soil microbes are using available nitrogen in the soil to feed, enabling them to digest the crop residues. This leaves little available nitrogen for the emerging seedling, so initial seedling growth can be compromised.

The system also allows for business expansion by enabling growers to plant twice the area in the same amount of time or to enable contracting opportunities for their neighbours. The agronomic benefits from this planting approach in the UK, is that crops often have reduced above-ground biomass which could help reduce the exposure to septoria building up in our warm winters. Reduced biomass also leads to reduced lodging risk which is important when large amounts of nitrogen fertiliser are being applied to the crop.





Spring peas planted into sprayed-off rye grass



Top right: Spring barley planted into sprayed-off rye grass

Below right: A very good example of winter wheat rooting, showing active root development and soil structure

9.2 Rotation and cropping

"A range of crops and livestock, grown in a rotation around farms, is the key to the sustainability of this intensive system" (Ministry for Primary Industries).

Driving around New Zealand one of the main differences in comparison to the UK was the diversity of crops being grown in the main arable regions of the South Island. This was certainly the case for Roger Lasham (*see next page, left*), agronomist at Turley Farms where 21 different crops are grown on their 5,295Ha in the Canterbury Plains region. The range of cropping is very diverse and includes Chinese cabbage, mustards, onions, radishes, beetroot, sweet corn and of course wheat, almost as a break crop.

Most of the farms growing high yielding wheat crops had a rotation that included two years of clover or rye grass grown for seed. This break from the cereal rotation enables the deep nitrogen-fixing roots of the clover to develop over two years adding organic matter to the soil. The organic matter locks up nutrients, making them available for subsequent crops as they decay or are broken down by soil microbes. With no soil disturbance, through a longer grass/legume rotation, the microbe populations increase enabling the recycling of nutrients





Roger Lasham, agronomist at Turley Farms

to be more efficient, making them available to the following crop. A white clover sward is capable of producing in excess of 180Kg/Ha of nitrogen (*Scottish Agricultural College- FFBC Farming for a better future*).



Having a grass/clover element in the rotation also opens up opportunities for the

integration of livestock into the arable rotation. Fattening lambs from grass/clover swards is a very efficient use of the field (paddock) before and after seed production. David Ward (*right*) who farms near Ashburton finishes 20,000 bought-in store lambs by grazing arable crops in this way. Livestock manure also helps feed the soil biology; all contributing to a healthy soil in which to grow high yielding crops.

Crops grown include grass seed of various varieties, wheat, barley, peas, rye, radish, peas, red clover, white clover, beet seed, kale, swedes, chicory, plantain and maize. One of the most logical and simple 9 year rotations is used by Mike Solari, near Gore (who is the current world wheat growing record holder) and follows this pattern:-

> Grass: Grass: Wheat: spring Barley: Peas: Wheat: Oilseed rape: Wheat: winter Barley



David Ward who farms near Ashburton



The highest yielding wheat crops have generally come from wheat following peas. The grassland is let to a third party whose sheep are used to graze the white clover and perennial rye grass paddocks. The fields are only grazed to ensure all the organic matter is recycled through the sheep back into the field and, with the clover being prolific in the second year, production of 14,000Kg/DM/year is being recorded.

A mixed cropping rotation enables different groups of active ingredients to be used to control pests, weeds and diseases, reducing the potential for chemical resistance. Different crops also give opportunity for reducing crop establishment costs within the rotation especially using spring and autumn cropping.

9.3 Wheat

I spent a couple of very educational days with Rob Craige, (Research Manager-Cereals) at FAR (Foundation for Arable Research) at the Chertsey demonstration plot site and their 20T trial site. FAR is a farmer-owned research organisation similar to NIABTAG and is involved in independent trials for their farmer members. The graph below demonstrates a couple of key messages that I wanted to explore in more detail with Rob - through the trials - and get a handle on what agronomic differences there are between wheat grown in New Zealand and the UK.



Graph Showing the Comparison Wheat Yields 1963-2013

Source: Foundation For Arable Research



An interesting observation for me was that the same genetics are producing almost twice as much yield in New Zealand compared to the UK. The group 2 milling wheat Einstein, bred by Nickersons in the UK, currently holds the world record but is a variety that does not sit on our recommended list as it appears 'outdated' by current standards. I do think that some varieties can suit certain climates or soil types and perform well in these areas, and this can only be learnt by on-farm trials and the sharing of such information. The graph also clearly shows the plateau effect of wheat yields in the UK, which is not happening in New Zealand at the current time.

I wanted to pick out a few of the interesting areas of research - from the 20T field research plots - which I think will have an effect on the overall wheat yield being grown here in the UK:

- Sowing date is very specific as the crop needs to be planted early to develop enough biomass through the growing season to maximise light interception (Appendix 11). A target date for drilling of the first week in September should ensure good root development and biomass accumulation. Field selection and weed pressure must be paramount, especially when dealing with blackgrass.
- Variety choice the ideal variety should be suited to early drilling and have excellent disease resistance. The variety must remain prostrate through the autumn with very slow development. Ideally it should flower early and be later to mature so the grain fill period is longer.
- Plant population a target population of anywhere between 450-500 ears should be enough to deliver a 15T/Ha yield, having targeted a population of 125 plants coming into the spring. Different varieties will have very differing tillering capacities and so seed rate will need to be adjusted accordingly.
- Growth regulation this aspect is very important to keep the crop standing and to maintain maximum light interception to all the leaves on the plant. The products available are very similar to those in the UK and are based around chlormequat and cyclohexane carboxylate. I saw some very interesting trials looking at autumn applications of growth regulators, which were working well.

Another option for growth regulation is through winter grazing. A reduction of above ground biomass and a reduction in leaf disease inoculum will reduce the disease pressure in the crop through the growing season. This was being trialled with the use of a topper rather than livestock. This option must be used cautiously as yield penalties can occur if the stock graze too long or too much and remove the





A trial plot of wheat that has lodged due to too high a seed rate, drilled too early with not enough growth regulation

growing point of the plant. The photo above was taken in December (our June) and shows a trial plot of wheat that has lodged due to too high a seed rate, drilled too early with not enough growth regulation.

- Fertiliser Soil mineral nitrogen samples are used regularly when assessing the level of nitrogen available through the soil. If following crops of peas, clover and grassland there is a high residual nitrogen level that needs to be accounted for when looking at crop requirements. The target would be to make available 25Kg/Ha per tonne of anticipated yield, so a 15T/ha crop would need 375Kg/Ha. As mentioned earlier, a clover sward can accumulate 180Kg N/Ha although the question is: when is that nitrogen available? In reality it isn't there immediately during the start of the rotation but should be factored in for the following 3-4 years. Timing of manufactured nitrogen is also key. In theory the soil mineral nitrogen and what the plant has attained through its root system, should keep the plant alive until Zadoks 32 when 60% of the nitrogen should be applied. The remaining 40% should be applied before Zadoks 39 (See Appendix 10).
- **Fungicides** Generally the fungicide strategy is very similar to that deployed in the UK. Obviously every year is different but the target is to protect every leaf as it emerges, from leaf 3 onwards:-
 - 1. T0 Triazole
 - 2. T1 Triazole/cholorothalonil
 - 3. T2 Triazole/Strobilurin, flag leaf timing
 - 4. T3 Triazole/Strobilurin, timed before flowering
 - 5. T4 Triazole/Strobilurin, 17-21 days after T3

The aim of such a high investment in fungicides is to keep the crop photosynthesising for as long as possible. Mike Solari's world record crop was in the ground for 51



weeks of the year and every day that the crop can maintain grain fill it adds 200Kg/Ha of yield. The final spray at T4 is not one that we would consider in the UK very often and is only used if there is great yield potential in the crop. Septoria tritici is the main fungi that reduces yield in New Zealand's wheat crops. Resistance to triazole and strobiliurin chemistry is becoming very common but, with the release of

the SDHI family of fungicides, the short to medium term control of septoria should be assured if these fungicides are used at the correct dosage and in mixtures of other chemical families. Appendix 12 highlights the distribution of green area at flowering which contributes to yield.

The UK and Europe will find themselves in an impossible situation when trying to control fungal diseases after 2017 when certain 'triazole' fungicides are removed from use. These includes epoxyconazole, metconazole, tebuconazole, fluquinconazole, diphenconazole and flusilazole (already removed) and will leave a wheat fungicide strategy based around SDHI chemistry which will increase resistance over a short period of time, potentially resulting in huge yield loss.



Rob Craige (Foundation For Arable Research) at a PGG Wrightson technical event.

9.4 Irrigation

Irrigation carries huge capital cost in terms of infrastructure and equipment so you need to be confident about the benefit it brings. There are two main sources of irrigation water in the Canterbury Plains: borehole and piped river water. Boreholes can be established relatively easily and, although metered - sometimes with remote wireless connection - the aquifer water is not limited. River water is pumped over longer distances and comes from the main three rivers flowing west to east through the region. Farmers have organised themselves into irrigation groups to pay for and run the infrastructure of pumps, pipes and channels. This shows that farmers are capable of working together to raise funds for major capital projects and to then to run them successfully.

The photos (*on next page*) are from Turley Farms where the circular pivot irrigator can't reach the corners of the field and easily demonstrate the positive effect of irrigation on the crop leaf area, greenness and yield potential. Roger Sylvester Bradley (ADAS) has demonstrated that a 2T/Ha increase in yield can be achieved with irrigation at the key grain filling time.



Growers such as Eric Watson use neutron probes to monitor moisture deficit and schedule irrigation accordingly. Eric also has his irrigation pumps linked up remotely via radio to a screen in his vehicle so he can see the pump output whenever he needs to. Others, such as Nuffield Farming Scholar Steve Wilkins, are using variable rate irrigation to alter the water volume applied to the crop depending on soil conductivity maps to reduce energy use and use the water resource more efficiently. The lower the holding capacity of the soil the more the irrigation equipment applied - as demonstrated by the pictures on next page of the variable rate irrigation schedule. Water volumes approaching 200mm can be applied to a growing crop of feed wheat at a cost of \$2/mm. One advantage that we have in the UK is our winter rainfall will nearly always fill the field to capacity. The key then is rainfall through the crop development phase and grain fill or the ability to increase field water storage through higher organic matter levels.



The circular pivot irrigator can't reach the corners of the field and the photos easily demonstrate the positive effect of irrigation on the crop leaf area greenness and yield potential.

Using precision farming techniques such as electro conductivity (*top of next page, page 53*) the water holding capacity of the soil can be measured. This then allows irrigation to be scheduled to the crop need depending on soil type. This technology can result in reduced water and energy use increasing yields where water is the limiting factor.



See pictures on next page of the variable rate irrigation schedule. The lower the holding capacity of the soil the more the irrigation equipment applied.



Electgro magnetic maps to schedule irrigation plans

Data from F.A.R. over two years suggests a 2.2T/Ha yield increase with irrigation from early drilling (March equivalent to September in the UK) and a 3.2T/Ha yield increase from later drilling (April in NZ is equivalent to October in UK). See Appendix 13.

9.5 Wheat growing record breaker

Mike Solari with his wife Margaret farms 176 Ha near Gore in the south Island of New



Mike Solari, current wheat world record holder

Zealand. Mike works with Graeme Jones (PGG Wrightson) Roger and Sylvester-Bradley (ADAS) and is the current wheat world record holder with a crop of Einstein wheat vielding 15.637T/Ha harvested on the 8th March 2010. To qualify for the record attempt the field must be at least 8Ha in size and have an independent adjudicator present to make sure the Guinness rules are adhered to.

The soil type is a silt loam over silt with some gravel in places, and the cool climate suits slow grain filling for high yields. All the crop residues are chopped and ploughed in to return organic matter to the soil, which is sub-soiled twice in the rotation before wheat, once after peas and the second time after oilseeds. Mike is sure that sub-soiling helps to structure the



soil, which has the tendency to run together, so no rolling post drilling is allowed. Mike aims to establish a modest plant population of about 100-110 plants in the spring with somewhere near 600ears/m2.

This plant (*see photo right*) had about 18 tillers; admittedly it was from a slightly below-average population but it just goes to show what potential there is for the plants to develop and tiller out with strong viable stems. The plants are not wasting energy by growing tillers and then aborting them. If this amount of growth appears above the ground then what are the roots doing to support this growth?

Fertiliser plans are mapped out at the start of the season - to feed for expected yield - and soil mineral nitrogen samples are taken to monitor the available nitrogen held within the soil. After the two years of grass in the rotation



This plant had 18 tillers

there could be as much as 140Kg/ha nitrogen available to the following wheat crop; although the highest yields have come further into the rotation after the peas. A total of 5 applications are used on the crop to steadily build the yield through the growing season. Fertiliser is used as a tiller management tool, when required, and Mike will be ruthless in holding back fertiliser until GS 31/32 if there are too many tillers - even to the stage of the crops turning yellow with tiller loss.

Prolonging the photosynthesis of the plants is also key, and keeping disease out of the canopy is of prime concern. A strong fungicide approach, aimed at septoria control, means that the high yielding crops remain in the field for 51 weeks of the year. It's this extended grain fill period, coupled with cool temperatures and good solar interception that Mike is sure accumulates the yield in the crop.

The picture at the top of the next page (*page 545* is of one of Mike's crops of Einstein, a variety that obviously does very well on the farm. Mike's attention to detail, spending time in the field, the rotation, timeliness of application, forward planning, passion and the love of growing crops all contribute towards a very productive farm with some of the best crops I have seen on this trip. It was great to finally meet Mike and learn about his farming philosophy, his aims and objectives.





One of Mike's crops of Einstein

9.6 Summary from New Zealand

My visit to New Zealand provided a real insight into what level of production can be achieved with the right climate and attitude towards food production. There are 5 key points that summarise my findings and cement the essence of my visit:-

- The attention to detail is second to none in both the livestock and arable sectors. This level of detail enables New Zealand farmers to maximise the marginal gains of the soil and climate in crop production. Knowing the cost of production and cost of purchase feeds - down to the value of cents/Kg/DM - meant a more balanced and fair trading relationship between farmers.
- Irrigation has a significant part to play in maximising the yields of all the crops grown, not just wheat. Although significant investment is required, having the ability to use this asset to fill in the 'rain gap', means significant yield increases can be achieved above those of the 'dryland' farms.
- The wide range of crops grown spreads market risk and enables more opportunities for niche crops to be grown. This diversity spreads harvest and business risk.
- The integration of livestock (cows, young stock, deer, beef and sheep) into the arable rotation enables a period of rest for the soil when organic matter can be increased. This forage element of the rotation can bring opportunities to enhance the rotational gross margin, rather than have a negative effect.
- The attitude of the farmers I visited and stayed with was very positive and progressive which was a real inspiration when looking at pushing the boundaries of trying different techniques and new ideas.



10.0. Ireland

My final visit took me to Ireland to visit farmers and researchers involved in wheat production - with different cultivation strategies in a climate normally wetter than ours. Ireland's arable area only covers 9% (378,000 Ha) of the farmed land but has some of the highest wheat yields in the world. Average wheat yield between 2008/11 was 8.93T/Ha

With Andy Doyle, Tillage Editor for Irish Farmers Journal

(Tillage Sector Development Plan).

My meetings were very topical and organised by Padraig Burke, from Novochem, to whom I am very grateful. We started with an overview of Ireland's farming history by Andy Doyle, Tillage Editor for the Irish Farmers Journal.

Andy's knowledge of

agriculture in Ireland was second to none and set the scene for a very interesting week. Andy's main comment on yield reduction related to soil organic matter and how it is being depleted in the Irish soils through cultivation. Coupled to this is the area of second, third

and even continuous wheat. Where big yields are still being achieved is when land is coming out of old pasture into the arable rotation. 1984 was a year of big yields in Ireland and, with today's genetics, an average yield of wheat would have been 13T/Ha.

Andy also spoke of the falling wheat area in Ireland. This is due to the increasing cost of inputs, weed pressure (brome and Andy also spoke of the falling wheat area in Ireland. This is due to the increasing cost of inputs, weed pressure (brome and cleavers), potential resistance issues and competition from hybrid barley.

cleavers), potential resistance issues and competition from hybrid barley. Fungicides and their effectiveness came up several times as a real threat to Irish wheat production especially when trying to control septoria and fusarium headblight. Headblight susceptibility seems to be linked to shorter varieties and growth regulation; both of which are favoured by Irish growers due to the wet climate and the need to keep the crop standing. With modern elite varieties having very similar parentage he feels that the gene pool is narrowing, resulting in the inevitable variety breakdown to disease. There is a legal requirement to produce green cover through the winter period, and growers are starting to investigate the opportunity of cover cropping for soil improvement. We explored different

Robert Wilson Wright (far left, Tom McCabe (right) and Padraig Burke (centre) assessing soil structure septoria disease pressure

rotations revolving around grass, cereals, cover crops (spring and winter), and a brassica and a pulse to add longevity to the rotation and maintain diversity both in crop risk and soil health.

In the afternoon we headed out to Coolcarrigan Farm in Co. Kildare to visit Robert Wilson Wright (far left) and were joined by Tom McCabe (*right*) from University College Dublin. Padraig Burke (Novochem) is in the centre.

Robert has been gradually moving away from full inversion tillage since he started planting with a Dutzi drill in the 1980s. Gradually he has reduced cultivation depth and for the last 5 years has been direct drilling. The farm receives between 800-1000mm of rain per annum. Organic matter levels on the farm are fairly consistent at 5.2%. Robert is gradually changing

the rotation, moving away from continuous wheat (average vield 8.9T/Ha), to include more oilseed rape and spring beans. No phosphate fertiliser has been applied for the last 5 years, with no detriment to yield or soil organic matter levels. Robert is convinced that, as the soil health improves through direct drilling, more nutrients held within the soil structure are becoming available to the crop as and when they are required. Even on the heavy areas of the farm direct

Soil structure on Coolcarrigan Farm

drilling is having a positive impact on soil structure. The picture above taken on a heavy land field clearly demonstrates 3 things:

- 1. Soil structure (crumbly and fine) has not impeded the rooting of the previous rape crop
- 2. Soil structure has been enhanced by the activity of the worms and the organic matter has been dispersed through its profile
- 3. This structure is not compacted, allowing the current crops roots access to the available nutrients and water without restriction

Padraig Burke and Steven Kildea

Dermot Forristal (right) and me

I met two very influential researchers at Oak Park (Carlow, Kildare) the regional Teagasc (Agriculture and Food Development Authority) research facility. Steven Kildea is a plant pathologist in the Crop Science Department and Dermot Forristal is the principal researcher in Mechanisation and Crops.

Teagasc's role in Irish Agriculture is for Research, Advice and Education. Oak Park is the main centre for disease control, fertiliser and nutrients with an element of grass and potato breeding. Some of the core funding is to look at and develop anti-resistance strategies specifically for septoria tritici. Researchers are looking at varieties, planting dates and

chemical mixes to avoid resistance. Resistant strains of septoria to 'azole' chemistry are well documented in Ireland (and the UK) and the risk is that the fungi will mutate to resist the latest family of fungicides (SHDIs - succinate dehydrogenase inhibitor). This is a major threat to wheat growing in the wetter, warmer climates

... the risk is that the fungi will mutate to resist the latest family of fungicides

such as Ireland and the south west of England. Having said this there is currently no known resistance to Chlorothalonil, which is included in most tank mixes when spraying fungicides to reduce resistance selection.

Dermot is involved in a very interesting project looking at the interaction of different crops in rotation, with different cultivation strategies (above right). The cultivation types include deep ploughing, shallow ploughing, min till and strip till. This trial is fascinating and is looking at individual crop gross margins as well as rotational gross margins. It would be good to extend this to net margins when cultivation costs are included. Part of the project is to develop a higher financial return from the break crops. In a longer rotation the percentage of break crops increases and so does their contribution to the rotational profit or loss. Break crops need more funding to make their rotational contribution more reliable but they can offer some great opportunities to reduce cultivation costs and weed burdens.

Philip Reck

Philip Reck manages 1,200 Ha of light to medium loam in a 20 mile radius of Enniscorthy, Co Wexford, Ireland. His cropping is cereals and oilseed rape, all min-tillestablished, with some areas of the farm growing continuous spring barley. The spring barley is contracted to Guinness to be roasted and as a result the area grown is increasing.

Philip has started to use cover crops over the winter period to comply with the legal requirement

but also as a way of enhancing soil structure and reducing erosion on some of the lighter, more sloping fields. Cover crops, such as hybrid kale and fodder rape, are planted with a single pass Vaderstadt carrier and biodrill combination before being rolled. Philip has been

min-tilling the farm since 1999 and for drilling in spring 2014 he purchased a 6m cross slot drill from New Zealand. This has the capability of putting seedbed fertiliser adjacent to the seed for maximum spring growth. I was joined by Jonathon and Nassau Greene, who visited Overbury earlier in the year, to look at our cross slot drill trials and who are exploring crop establishment by direct drilling on their home farm.

Worldwide, on approximately 155 million hectares, successful and progressive farmers are growing crops using Conservation Agriculture

After an amazing visit to the Coolmore Stud, Padraig and I met up with fellow Nuffield Farming Scholar (2004) John Geraghty and we spoke in great detail about my subject and how soil impacts so significantly on the farming system. John is heavily involved in conservation agriculture (CA) and its three main areas of soil improvement are:

- Minimal soil disturbance
- Permanent soil cover with plants or residues
- Use of crop rotations and cover crops

Worldwide, on approximately 155 million hectares, successful and progressive farmers are growing crops using CA practices. Neither plough nor cultivation implements are used for establishing a wide range of crops. The total area is roughly three hundred times the entire tillage area in Ireland and it is increasing on an annual basis.

Direct drilling was very popular in the 1970s, after the Moore Unidrill was launched, allowing farmers the opportunity to significantly reduce establishment costs. The system soon failed due to limited chemical control of weeds (2,4D and paraquat were the only herbicides), little understanding of rotations and no cover crops to suppress weed growth and build soil organic matter. Burning was also used as an option to remove crop residue but this increased the populations of annual meadow grass (Poa annua L.) and sterile brome (Bromus sterilis L.) The cultural control for these weeds was ploughing which defeated the direct drilling theory. Drill technology was also limiting as crops struggled with poor establishment and vigour.

John reaffirmed much of what I had learnt through my Nuffield Farming experience. Soil health is vital to what we are trying to achieve; it must be our number one priority. It is a complex living being, not just a medium to produce food. In a woodland scenario, where the soil is undisturbed it carries a higher fungal

Soil health is vital to what we are trying to achieve; it must be our number one priority.

population than bacterial, whereas is an arable scenario the balance is reversed limiting growth and residue breakdown. Table 3 demonstrates that the uptake of Conservation Tillage has significant financial and ecological benefits:-

Crop Establishment System	Cost Euros/Ha	Work Hrs/Ha	Diesel L/Ha
Plough-Based System	135-170	3.4-4.2	35-50
Non-Inversion Tillage	120-135	0.9-1.1	15-25
CA and No Tillage	55-70	0.4-0.6	7-12

Table 3 : Crop establishment data for costs, work hours and diesel consumption

(Source: Soil Management Initiative (United Kingdom 2006)

Historically farmers have resisted the use of cover crops in the rotation for the following main reasons:

- The first issue is due to the uncertain timing of the nutrient release to the following crop. Nutrients are held in the plant residue and released when broken down by soil organisms. The speed of the breakdown is related to the soil temperature, moisture, aeration and soil microbial populations.
- 2. The second resistance is due to the perceived increase in slug populations. Slugs are detritus feeders, as shown in the picture overleaf (*page 61*) which had been taken in one of Richard Wilson-Wright's fields earlier in the week. These field slugs were feeding on last year's bean residue and not touching the wheat plants. Slugs are a problem but I feel that by not disturbing the soil habitat, and with reduced

insecticides, populations of their main predator, the carabid beetle, should increase to help control the population naturally.

- 3. The third issue is dealing with the large volumes of cover crop residue.
- 4. The final concern relates to the potential disease build-up when growing similar families: e.g. brassicas as cover crops plus as a cash crop in the main rotation. This can be managed by avoiding growing a related cover crop for the next two crops in the rotation. Also, due to the fact that the cover crop was not in the ground for a long enough period of time, it's time as a host was negligible in the cycle of disease build-up. Again, by growing a diverse mix as cover crops, the percentage of that species within the mix is greatly reduced, which would correspond to a lower field population of slugs.

Two other keys points brought up by John also made perfect sense, namely :

 Having flexibility within the system and doing things at the right time when the soil is ready. That might be difficult to do every season and will require patience, but it's a good place to ideologically start.

• Ensuring that fixed costs of the business set up to be low and flexible enough to still return a net margin in seasons where higher returning crops can't be planted.

This was evident in the UK in 2012 when many winter crops could not be established due to the wet weather.

10.1 Summary from Ireland

- As a crop establishment system direct drilling can perform very well in a climate considerably wetter than our own. With up to 40% more annual rainfall the system can perform if the soil structure is maintained.
- Maintenance of the soil structure will revolve around a good rotation, direct drilling, cover cropping, harvest traffic and residue management plus having the flexibility to change plans when the weather goes against you.

- Control of septoria tritici will become increasingly difficult with resistant strains evolving and fewer active ingredients to tackle the problem. By reducing the range of active ingredients we will be speeding up the selection of resistant strains, which is not sustainable going forward, unless new active ingredients are developed.
- The use of hybrid barley as an alternative to wheat, with similar yield but with lower growing costs and better disease control, is starting to make growers look at the crop in more detail.

Maintenance of the soil structure will revolve around a good rotation, direct drilling, cover cropping, harvest traffic and residue management

11.0. Management steps to increase wheat yields:

My study tour now being completed I would like to summarise the lessons I have learned and relate them to wheat growing in the UK.

Improved soil health and soil	Zero till is essential.
condition	A longer rotation with greater diversity of crops.
	Do not leave bare land, cover crop whenever possible.
	Livestock integration.
Build soil organic matter levels to	By doing all the above.
over 5%	Use organic manures if available.
	High wheat yields will usually follow peas.
Direct drilling	The right drill is absolutely key to deal with larger
	amount of crop residue.
	Drill slightly earlier than conventionally and use seed
	bed phosphate fertiliser to encourage root
	development.
Choose your variety carefully	Suited to early drilling, remaining prostrate through
	the autumn, flower early and mature later.
	Have excellent disease resistance.
	Aim for between 450-500 ears at harvest.
	Avoid fields with excessive grass populations.
Growth regulation	Very important. Can be achieved chemically but
	alternatively by autumn/winter grazing with livestock
	to reduce above ground biomass and remove disease
	infection.
Irrigation	If available, consider application during grain fill.
	Monitor soil moisture deficit as yield is lost before
	symptoms are visible.
Nitrogen fertiliser	Applications by regular soil and tissue testing.
	Timings of nitrogen fertiliser to coincide with grain fill
	once canopy is produced.
Fungicides	High investment necessary – target is to protect every
	leaf as it emerges.
	Mix active ingredients to reduce resistance threat.
	After 2017 certain 'triazole' fungicides will be
	removed from use putting extreme pressure on wheat
	production.
Harvest and store management	Timely harvest and correct storage ensures that
	maximum yield and quality are retained.
Attention to detail	Regular time in the field monitoring crop
	development to ensure timely applications.
Record Reeping	Record and interrogate applications such as rates,
	timings and climate to better inform the next
	decision.

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12.0. Conclusions from my study tour

- 1. The genetic potential is already present in our current wheat varieties to achieve over 20T/Ha and, with genetic improvement, this will continue to improve. Spot yields in New Zealand have been recorded at over 20T/Ha. Future breeding programmes need to prioritise disease resistance, water use efficiency plus drought tolerance ahead of yield.
- Improved soil management holds the key to increasing yields on farm.
 It is under the farmer's control and will result in the platform for improved agronomy. Improving the soil on farm will come from:
 - Zero tillage increases organic matter to hold nutrients in the soil and naturally improves field drainage and soil stability within the field. This will reduce soil erosion and therefore result in improved water quality as well.
 - Longer, more diverse rotations will result in a wider spectrum of crops grown to keep a more active population of soil flora and fauna. Higher populations of fungi will be able to break down crop residues more efficiently making them available to the crop. These rotations will reduce the reliance on fewer active ingredients, producing a more resilient rotation.
 - Cover Crops will help build organic matter within the soil aiding the sequestration of carbon from the atmosphere, giving another opportunity to remove compaction by rooting development and feeding the fungi within the soil. The decaying roots will also provide good drainage channels and easier rooting for the following crop if not disturbed by cultivation.
 - Livestock Integration the addition of livestock, with the inclusion of a forage-based element in the rotation, either grazing cover crops or forage crop, will play an important role in enhancing the soils structure, both physically and biologically.

continued on next page

- 3. Precision farming techniques need to be used to focus crop inputs on the areas where the yield potential is greatest, maximising economic return.
- 4. Weather monitoring and the gathering of data will build up a picture about how crops perform on farm during different climatic events. This knowledge can then be used in subsequent years to make more informed decisions.
- 5. More funding should be made available to look at the key issues around soil health, impact of rotation and how the plant interacts with the microbes and fungi in the soil. This will be a long term research investment which will not product instant results but nevertheless should be funded, instigated and followed up.

The "word cloud" below is taken from the summaries from the different countries I have visited in my Nuffield Farming study tour looking into breaking the wheat yield plateau and highlights the essential aspects of:

- Soil
- Cover Crops
- Livestock
- Organic Matter
- Genetics
- Irrigation/Rainfall

13.0. Recommendations

In order to break the yield plateau in the UK, the arable sector needs to: 1. Improve our individual farm soil health and soil structure to be more resilient in changing weather patterns and climate, enabling the genetics of our elite varieties to deliver their maximum potential. This will be achieved by the four pillars of: zero tillage diverse rotations cover cropping, and livestock integration making a more sustainable and profitable arable sector. 2. As an industry we need to develop, trial, test, and then use new biotec solutions to deliver a more integrated, sustainable solution for arable production. This genetic solution could enable a reduction of inputs (fertiliser, water, insecticides and herbicides) that will increase profitability and biodiversity within the sector. 3. Build even closer relationships between academia and industry to speed up the flow of knowledge transfer and to initiate discussion about solutions for industry issues. This should be done on a national and international level, with the experimental results and conclusions made available to farmers and growers quickly and effectively in a way that is easy to understand and that can be implemented at a farm level. 4. More scientific research and trials should be undertaken to fully understand the benefits of cover crops as they will form the backbone of many farming rotations in the future. This will be the primary method of soil enhancement to improve the organic

matter, remove compaction and aid weed suppression.


14.0. After my Nuffield Farming tour

From the onset of my Nuffield Farming study trip to North America I have been actively involved in implementing novel ways of improving crop husbandry techniques and soil management. I have always hosted on-farm trials as a way of seeing first hand the impact on yield or quality of certain applications, products or techniques. These trials are expanding to look at crop nutrition through trace element tissue testing and subsequent follow-up applications. I am also looking at variety trials on the farm to see what cultivars perform best on our different soil types.

As a result of my Nuffield Farming Scholarship I have started direct drilling with both a local contractor, as well as our own cultivator drill. Crops of oilseed rape, winter wheat, spring wheat, spring barley and peas have been established this way since autumn 2013. The long term benefit of this establishment system means that the fields will need to be treated the same way for several seasons to gain the maximum benefit from direct drilling. I am exploring the opportunities of moving to a complete direct drilling system to improve soil health and soil structure, which will improve yields, reduce costs and improve the water quality of the environment in which we live. Water quality is important to the farm as we supply local residential properties. A key element to the success of the system is the investment in the correct drill, which has to be able to: -

- cope with increased crop residue whilst maintaining accurate seed placement
- incorporate fertiliser at the time of drilling
- have minimal soil disturbance, to reduce the weed burden
- be robust enough to withstand the Cotswold brash stones and plant into our wide ranging soil types from heavy clay through to sand soils.

I am also investigating widening the crop rotation on our heavy clay and sand soils to encompass a 2-year grass and clover ley and increasing the farm's sheep flock to utilise this extra forage. The 7-year rotation is likely to include at least two over-winter pre-spring cover crops to continue to improve the organic matter in the soil and help prevent water run off and soil erosion. The cover crops will be utilised by the sheep through the winter period, increasing the amount of natural re-cycling of the plant nutrients plus adding biology to the soil. This expansion in available forage will also enable an expansion of the sheep flock enterprise.

My Nuffield Farming Scholarship and the Nuffield alumni have widened my agricultural and scientific network of contacts, which enables me to challenge industry preconceptions of what is achievable - or not - in more depth.

Jake Freestone



15.0. Executive Summary

"To feed our growing global population, we will have to produce the same amount of food in the next 40 years that we previously produced in the last 10,000 years". Dr Norman Borlaug.

Wheat yields in the United Kingdom have plateaued for over a decade despite increases in genetic potential by plant breeders. My study sought to understand how we could get closer to the genetic potential in the field.

The key factor to achieve higher yields in conventional farming is through excellent soil condition. Farming practices - including shorter rotations, maximum soil disturbance and the loss of a mixed farming system - have led to a depletion of soil organic matter and soil microbial activity, preventing the current genetic potential from being achieved.

Minimal soil disturbance, which I experienced in Alberta and Oklahoma, through the adoption of zero tilling or direct drilling, significantly reduces soil mineralisation and starts to increase soil organic matter. By not disturbing the soil, microbial populations increase, speeding up the breakdown of fresh crop residue and recycling the nutrients back to the following crop at a faster rate.

Introducing a longer rotation, including legumes, grass and spring cropping; to fix atmospheric nitrogen, reduce compaction and enable cover crops to be grown; increasing soil organic matter further, as is common practice in New Zealand, all assist this aim. Spring cropping also disrupts pest, disease and weed cycles.

Cover cropping maintains a living plant in the soil during periods of traditional fallow. In South Dakota I saw examples of how cover crops help reduce soil erosion, fix atmospheric nitrogen, assist in the removal of compaction, trap essential moisture and increase microbial activity.

Livestock integration improves soil by bringing manure and utilising cover crop green matter as well as returning fibrous material to the soil. I saw excellent examples of this in North Dakota.

Soil condition alone will not achieve 20t/Ha but is the key component. Genetics, climate, husbandry, water availability and the best in-field management are needed to support a resilient, sustainable farming system capable of breaking the wheat yield plateau. However, the removal of key active ingredients used to control disease, coupled with the lack of research into genetically modified crops in Europe will make future advances in crop yields challenging, if not impossible in some parts of the country.



16.0. Acknowledgement and Thanks

I would first like to thank my family and friends for believing in, and then supporting, me on my Nuffield Farming Scholarship, both during the research phase and also when travelling. I would also like to sincerely thank Penelope Bossom at Overbury Farms for her support and commitment to the project and the on farm team for taking responsibility and relishing the challenge of carrying on in my absence. It would not have been possible without the very kind sponsorship of the Central Region Farmers Trust and I hope reports like mine will be seen as a valuable addition to our industry and will encourage more organisations and companies to sponsor future Nuffield Farming Scholars.

A huge thank you must go to all the #Nuffield13 Scholars from around the world for their help, support and friendship since the Contemporary Scholars Conference in March 2013 and especially to Andrew Williamson, Tom Sewell and Natasha King for sharing some of the road trips with me.

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17.0. Appendices

Appendix 1 - World Population 2010-2050







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Source: NIAB/TAG



Appendix 4 – World wheat production and Consumption

⁷¹ Source: The Hightower Report June 2014





Appendix 5 - Examples of different green area indices in wheat

Source: Home Grown Cereals Authority Wheat Growth Guide

Appendix 6 - Nutrient Uptake of a typical 8T/ha Wheat Crop



Source: The Potash Development Association



Appendix 7 - Potassium pathways and soil reserves



Source: The Potash Development Association

Appendix 8 – Public expenditure on R&D activities improving agricultural production as a proportion of GDP.



Source: The Taylor Review: Science for a New Age of Agriculture



Appendix 9 - Wheat yield from Oklahoma State University cover crop Trial harvest 2014

Yield (bu/acre)	Cover crop treatment
22	Cowpea, Sunn Hemp
28	Cowpea, Sunn Hemp, Buckwheat, G. Millet, Laredo Soybean
21	Cowpea
18	Cowpea, Mungbean, Laredo Soybean, Sterile Sudan, P. Millet
23	Cowpea, Mungbean, Sunn Hemp, Laredo Soybean
23	Cowpea, Sunn Hemp, Radish, G. Millet
24	P. Millet, Sterile Sudan, G. Millet
19	Cowpea, Sunn Hemp, Sterile Corn, Sterile Sudan, Sunflower
	Topdress N rates (lbs/acre)
25	0
22	30
17	60
22	90

Source: Assistant Professor Jason Warren Oklahoma State University

Appendix 10: Zadoks cereal development Scale



Source: Home Grown Cereals Authority Wheat Growth Guide

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Source: Home Grown Cereals Authority Wheat Growth Guide



Appendix 12 - Distribution of green area at flowering



Source: Home Grown Cereals Authority Wheat Growth Guide



Appendix 13 – Yield differences between drilled dates and drying verses irrigated sites in New Zealand





Source: Foundation for Arable Research (New Zealand) 17.0 Bibliography



Appendix 14 – Bibliography

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