



Nuffield Farming Scholarships Trust

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The Gordon Newman Travel Award

**The Prospects for Grain Maize in the UK
under Climate Change**

Alistair House

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1. Introduction and Acknowledgements

This report is the result of an 18 month travel scholarship co-funded by the Nuffield Scholarships Trust Travel and the Gordon Newman Travel Trust. I am greatly indebted to both of those charitable trusts for the opportunity that the kind offer of funding has brought to me as an individual and hopefully to the benefit of both farmers and agriculture in the UK.

The two Trusts annually sponsor scholars to travel and report back to the farming community at large in order to disseminate the information gathered. More detail on both Trusts' activities can be found in the websites below or contact the author directly.

- <http://www.nuffieldscholar.org> for **The Nuffield Farming Scholarships Trust**
- and The Gordon Newman Trust through the **UK Maize Growers Association (MGA)** at <http://www.maizegrowersassociation.co.uk/>

2. Personal background

I farm in Somerset in partnership with my brother and bought the family farm from a large institutional landlord in 2000. We have evidence that the farm had been a dairy farm for at least 500 years, but in 2004 the 120 cow dairy unit was closed due to lack of opportunity to expand it. The arable side of the business was allowed to grow alongside a contracting business. Other diversifications include a village shop, coffee shop, Post Office and an engineering business.

The arable business endeavoured to find a better rotation - and to enable better use of available waste streams. New break crops were tried but, for many of the reasons described below, maize was chosen. However, the look of the overall budget improved when both 50% maize and 100% maize were budgeted for.



Machinery utilisation became the driving force in the rotation when continuous maize was trialled. Now the farm grows around 350ha of grain maize, with 10% wheat retained as a risk reduction tool. Approximately 10% of the maize is drilled under plastic film for the same reason. Drying facilities are limited but capacity is boosted by sending grain to a farmer with surplus capacity.

The combine is hired in via an 'out-of-season' deal. The self-propelled sprayer and main tractor were sold as utilisation was poor under the new regime. Margins have improved dramatically, soil structure has improved and, with inputs reduced and the harvest spread over 3 months, we feel that risks have reduced.

3. Travels during my Study Tour

To investigate the two main aspects of my study, maize and climate change, I began by attending a conference in the Netherlands. The Joint International Agricultural Conference (JIAC) comprises three other European Institutions (ECPA, EFITA, EPCLF- see bibliography). Europe has a highly developed research and development network but with less advanced extension to farmers. There is a need for more funding and with many farms being small and fragmented, uptake of advice will be slow. (Average farm size EU27 is 12ha, 2009).

The next port of call was the USA, with its wealth of knowledge and advanced research including Genetic Modification (GM). Extension work is good and yields are high. Understanding of Climate Change (CC) matters were, however, slightly more reserved or even suspicious. I visited several farms, the Chicago Board of Trade (CBOT) and had meetings with the United States Department of Agriculture (USDA) in Washington. Various seed breeding facilities were visited, including Monsanto and Pioneer.

I then moved down into South America where Argentina and Brazil are already major international producers of grain maize and increasing their output year on year. Here the changes have occurred much more recently, many within 10 years. Capital investment is high, research is current and there is a good understanding of climate matters. With the El Niño/La Niña Southern Oscillation (ENSO) being so important to the agriculture of the region, there is a greater awareness of natural cycles.

In Argentina visits to farms and businesses, government and researchers gave me the impression that their largest 'variable cost' was their government intervention. Whilst the lack of regulation had allowed the rapid, (perhaps meteoric?) change from grassland/beef into soya/maize production, there was no doubt that the government was happy to make fairly impulsive decisions, some of which are considered to be ill-advised by many of the farmers.

The main Cargill oil processing plant, further farms, export facilities and growers were visited. The government representatives were harder to meet as interpreters were tied up on matters of national importance.

The travelling that I underwent during my study tour was fundamental to my findings, for much of the process of change can only be seen on the ground, by being there in person and by interviewing farmers, advisors and officials. In many cases, individuals can only speak openly when interviewed in person. I cannot begin to list the individuals concerned, but I am full of gratitude to them. The way that time was offered freely by fellow farmers and agriculturalists was quite astounding. I am sure that only in our profession is this the case.

I met and interviewed delegates from other countries at the two major conferences that I attended, and this fed me with further information on the growth of maize around the globe. Its relative importance versus sugarcane (another C4 crop) in South Africa, or tea in East Africa was well described by consultants. I also followed up contacts within the Nuffield network in New Zealand where ideas to counteract frost damage using fertiliser were learned. Australian contacts discussed the progress of climate change across south western states where proposed cropping changes would enable farmers to maintain a living, whereas continuing with traditional cropping might have become too risky.

4. Executive Summary

The report findings are presented here with the caveat that they represent only the views of the author, and not necessarily those of either the Nuffield Farming Scholarships Trust or The Gordon Newman Trust.

The report describes the author's premise that climate change in many of the world's temperate zones will cause warmer growing conditions. Many of these areas are currently growing wheat, which is the 'poor relation' of other semi-tropical crops, e.g. maize or sugar cane, which are C4 carbon cycle, and biologically different in their assimilation of CO₂ (*C4 cycle vs C3 cycle - see Appendix D*). A small increase in temperature will cause conditions for grain maize to become a strong contender in the UK rotation. This in turn may oust wheat and barley from the rotation.

Whilst there are other reasons why a farmer might continue to grow wheat, there are a number of agronomic reasons which could accelerate the shift towards maize. Other countries have seen very fast shifts towards alternative cropping regimes, such as that seen in Argentina from cattle ranching to soy production. This can have dramatic effects on social patterns and food price volatility on a worldwide scale.

It is important to attempt to quantify any such potential shift in production – consequently any improvements in infrastructure can be planned from an early stage to make the best use of any '*improving*' climatic conditions.

5. Background to the study: history of maize in the UK

Following the introduction of forage maize in the 1970s the uptake of *grain* maize in the UK has been rapid. (Morgan, 2010). Many reasons are given for this increase - mostly purported to be improvements in breeding. Climate change may have been a factor, but this was not a widely-regarded concept until the early 1990s.

Breeding alone may not be the only driver as there have also been technological changes in harvesting equipment. (For example in 1970 a single row harvester might have been capable of cutting 120t/day. In 2010, the largest harvesters are capable of 3500t/day).

However, the potential for *grain* maize in the UK is now gathering interest with much of the equipment being available from the traditional cereal rotation.

Grain maize today is generally a hybrid, which means that home-saved seed is not an option. In consequence, seed sales by the main seed breeding firms will give a measure of areas grown. (Albeit that seed rates will be under the control of the grower). The same information has been gleaned from France, USA and Argentina. (Burge, 2010). What is not known, though, is what proportion ends up as forage or is taken through to combining as a dry or moist, crimped product.

The gross margin of the crop being grown will always be the key driver of the uptake of the crop. Current gross margins for 2010 can be found in Appendix B and prospects forward to 2050 are dealt with in chapter 7.0. The gross margin of the grain maize crop compared with wheat is most sensitive to the following variables - yield, seed cost, fuel cost (mostly for drying).

If time had allowed, it would have been useful to get an accurate relationship between fuel cost and fertiliser, then all of the major energy inputs could be included as a fuel equivalent. Maize has a higher proportion of drying costs and this factor would lead to a useful assessment of risk management against volatility of fuel price.

There are budgetary reasons why a crop will appear to be showing a superior gross margin; i.e. the way in which we have historically costed our crops - e.g. some of the costs associated with wheat, particularly drying and spraying costs, are covered under overheads rather than variables, which can alter the relative margins. It is important to adjust this so that accurate comparisons can be made.

Other factors will play an important role in the decision making process during the planning of a crop rotation. They can be categorised, but it is harder to quantify some - such as political price manipulation.

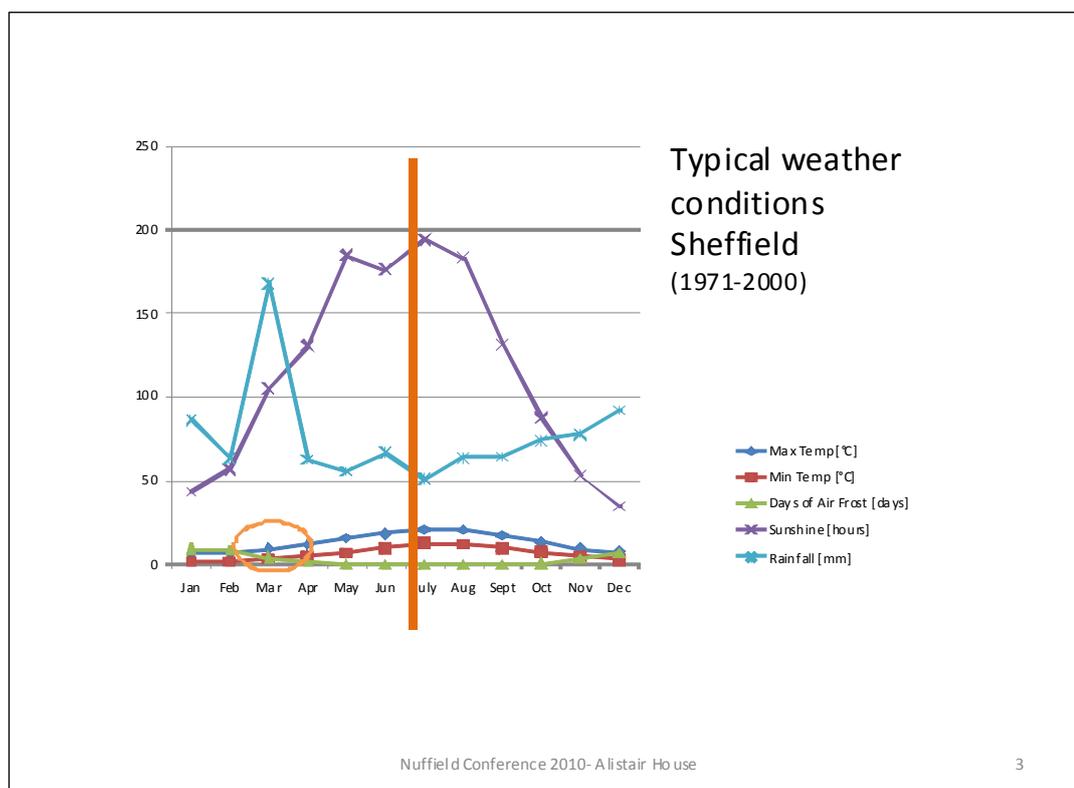
This has been apparent in Argentina where the government decided to cap the price of two staples in the diet - wheat and beef. In the case of wheat, farmer co-ops have published data on a website in an attempt to reverse the government decision. It is apparent that capping of internal prices has dramatically reduced the area under wheat. Then the shortage has driven the price towards the level of imported material (with consequent freight costs) and the reverse of the original goal has been the result.

Another example of government intervention is China, whose constitution includes a remit to maintain a minimum quantity of pork meat for home consumption. (estimated at 47mT in 2010 rising to 97mT by 2015). In the latter case, the difference is that a minimum quantity has been set, not maximum price, the effect being a positive incentive to its producers.

An example of where this has not worked is in the case of the EU Common Agricultural Policy (CAP) in the 1980s which, having reached its goal of minimum quantities, failed to scale back the targets, and so over-production consequently had to be exported with the help of subsidies.

6. Analysis of the current situation

A summary of this report was originally presented in Edinburgh November 2010 and in it a rather flippant suggestion was made - that UK farmers are not making use of the natural advantages of their weather. The graph below shows the min/max temperatures along with rainfall and sunshine hours for a typical site in the centre of Great Britain.



The orange vertical bar shows the rough position of the start of senescence of most of the mainstream cereals in UK. It was put to the audience that the energy received from the sun - which translates into the form of temperature at ground level - is not currently made full use of. The energy received after the orange bar is somewhere near half of the yearly receipts, plus the latter half of the year is somewhat 'wasted'. It is accepted that an autumn following crop will utilise a portion of the remainder to establish.

The solution of course is to grow a crop - such as maize, which will not be ready for harvest until October/November of the season. The following crop must almost always be a spring drilled crop, and as is developed in chapter 7.0, the potential for yield increase is an exciting prospect.

The orange oval in March acts as a reminder to the grower to watch the green line representing the number of days of air frost expected. In the example above, the number of days in March is 1.2 days. The number of days of air frost should be closely monitored in future projections.

Current margins

Much work has been undertaken on the matter of agronomy and current marginal analysis. It would be inappropriate to redo much of this good work. For example very good information on the current advice for growing the crop can be seen in work by Jonathon Burgess (*Burgess, 2008*) and a comprehensive survey work by Briony Burge (*Burge, 2010*), which looked at the current margins in 2009 (see Appendix B). The margins show an average position, where yield is the main driver in the gross margin. The variability can be hidden in the process of averaging and this needs more clarification.

To analyse the current cropping and margins in the UK and take into consideration any medium term advantages of grain maize in a potential arable rotation, then both actual and potential benefits should be considered; The following aspects are discussed in subsequent pages:

Strengths	of maize in UK current rotations
Weaknesses	of maize in UK rotations
Opportunities	for maize (potential for variable cost reduction)
Threats	to maize as a future candidate in a rotation (or weakness in the current cereal rotation)

6.1 Strengths of Maize in the Current Rotation

1. Margins of break crops

The difficulty in finding a new break crop - or a rotation where *every* crop has a good margin.

The relative margins of the first wheat crop vs. the second are well documented showing a fall in yield on a second wheat in the order of 1.5t/ha. With similar variable costs, the second wheat crop has a near zero margin. (*Nix, 2010*). It was not uncommon for growers to consider 'set-a-side' as an option whilst that regime was in place. This had the effect of allowing a first-crop wheat twice in a four year rotation, without putting oilseed rape closer than every four years.

2. Longer rotations are less flexible

and can be less efficient on smaller farms where, for example, a 7 year rotation might have one crop on 1/7th of the farm, which increases the separate storage facilities and management of a wide variety of crops.

3. Lack of profitability causing low investment

In many cases, investment in new technology has been poor and so to invest in a different technology would mean that it would have to be planted/harvested with existing equipment.

4. Risk management strategies

Farmers being used to lower margins are bound to be more risk averse when it comes to new crops, especially if a crop failure could have dire consequences.

5. Nutrient management

Arable cropping has been seen to be a useful outlet for livestock waste streams. This has led to a compromised situation between an autumn planted crop having manures ploughed under before planting - causing either leaching of nutrients, or very lush over-winter growth – which can require heavy disease control to maintain yield.

6. Potential loss of chemicals in the 'armoury'

There are active moves to remove many chemicals from the permitted lists - so reducing the options to agronomists.

7. Weed resistance

is building in certain areas and is causing concern for the future of current rotations.

There are areas in eastern England where the problem has reached critical levels. Winter fallows and the chemicals associated with maize are increasingly of interest to growers where blackgrass has become a major problem.

The above problems are current, real, problems for UK arable farmers and so solutions are constantly being sought.

6.2 Weaknesses of maize in current UK rotations

1. **Maize *within* a rotation** is difficult to return to a following autumn sown crop. It is certainly possible, but currently not wise to budget for more than 20-30% of the area to return to autumn cropping without harvesting grain maize early, (and the consequential penalty of higher drying costs). Proponents of drilling under plastic film suggest that film-drilling is one way to bring forward harvest dates.
2. **Secondary problems with wheat** following maize are high mycotoxin risk in the wheat crop. This can result in other control measures being required such as separate storage, good drying and good store management.
3. **Maize grown as a mono-crop** (i.e. continuously, and without a break) would have some concerns over disease build-up (although these appear to be less critical in practice). Maize appears to suffer from disease pressure far less than conventional cereals.
4. **Late frosts** could affect a large part of the crop if drilled too early (the current advice). Planting a proportion under plastic film may help to alleviate this risk. Evidence from New Zealand shows that a spray application of aqueous ammonia or urea could be a useful tool to combat this dilemma.
5. **The potential outlets for the grain** may be limited, but it is felt that the market will grow to absorb this increase. Currently there are quantities of grain being imported from the near continent. These might not be required, or some millers might include maize at the expense of wheat. Until there is sufficient quantity of grain maize, though, most compounders will not consider UK maize due to inconsistent availability.

6.3 Opportunities for maize (potential for variable cost reduction)

Maize has other natural agronomic advantages:

1. **It is of sub-tropical origin:** its C4 nature means that it will make maximum use of any temperature increase due to climate change. Approx 60% of maize is GM in the rest of the world. There are potentially strong benefits for maize if GM became politically acceptable in Europe. (The range of GM traits available to UK might be greater by the time that it is permitted). For wheat however, there are few biotech seed companies working on wheat traits which would be of immediate benefit. One presumes that this is in part due to the fact that home saving of seed means that collection of royalties is more arduous.
2. **Row spacing:** The current 30" (75cm) row spacing allows for the possibility of inter-row work, not yet possible with other crops. GPS technology allows for inter row cropping and planting with high precision RTK equipment (see glossary). This can be extended into controlled traffic techniques.

(see <http://www.controlledtrafficfarming.com/content/default.aspx>).

As temperatures rise, then the crop can withstand higher populations, but counteracted by any shortage of rainfall. There is consequently a wide range of recommended seed rates from approx 32,000 per acre to 50,000 per acre.

3. **Inter-row weeding:** Camera systems are now readily available to recognise rows of established plants - which in turn allow closer hoeing in the row and a higher speed of operation. Some tests have found higher yields from this method of weed control, although it has been associated with the nitrification of the soil due to disturbance.
4. **Inter-row band spraying:** Similar to the above method, and allows for a pre-emergent spray to be applied with the drilling operation above the crop row. This is followed by



an inter-row 'hooded' band spray of roundup. This has the potential to cut herbicide costs to less than £20/ha. (Mellander, B; Endure network, 2008) (www.endure-network.eu).

5. **Intra-row weeding:** is now possible with vision systems to 'see' and recognise the individual plants in the row. One method uses a rotating kidney shaped disc to cut weeds allowing the stem of the plant to miss the hoe on each rotation. (see <http://www.youtube.com/watch?v=Ny3Mjk-zaKY>). This technique is slow but can be used in organic systems, although it is relatively uncommon commercially. The system was originally designed in Britain by Silsoe Research Institute, and has been developed and brought to the market by Garford Ltd. (Tillett N, 2005)
6. **Direct drilling (DD):** DD is commonly used worldwide, but soil conditions, lack of equipment and farmer resistance are proving to limit the amount of maize drilled in this way in Europe. There are further savings to be found as fuel prices rise relative to grain price. It appears to suit spring cropping very well.
7. **Inoculations:** Bacterial/fungal seed inoculations are practical ways to induce improved phosphate absorption in the root zone. The practice is common in maize and other crops such as soya in South America and Asia. As yet, none of the popular inoculants are available in UK, but licenses for *Pseudomonas aeruginosa* are being applied for.
8. **Bio-degradable Plastic film drilling:** Often used in marginal areas, the plastic film is laid over the seed which is planted with a conventional precision drill. The grades of film have been developed to break down in a combination of moisture and sunlight. A design of one Irish built planter has the holes pre-punched into the film, but then the film is laid with the holes not directly above the seed. This has the effect of encouraging the plant to grow prostrate under the film until it gains enough strength to break through the film. This forces the plant to spend several extra valuable weeks under cover, which builds temperature receipts rather than the plant being open to the atmosphere any sooner. (see www.samco.ie)
9. **Potential yields:** The current maximum achievable yield of a maize crop is estimated to be around 37t/ha and the current UK average is thought to be around 8t/ha. Budgets are often created around this average figure but, due to the variability of results, the range of yields experienced is large. Forage trials in the UK are conducted by the National Institute of Agricultural Botany (NIAB) and part operated by the MGA. It should be noted that not all of the main seed suppliers are part of these trials. One interesting factor when looking at the trials' results is the wide range of yield from the control to the highest and lowest yields. This is indicative that the trial results themselves should be treated with caution. (R^2 confidence levels need to be born in mind).
10. **Hybridisation:** The maize crop is usually developed as a hybrid from two normal varieties, and this gives 'hybrid vigour' to the newly developed seed. That seed will grow and mature, but the grain that it produces will not grow to maturity. This means that no farmer-saved seed exists. There are circumstances in developing countries where non hybrid maize is grown, but with consequent lack of vigour. There are moves towards persuading the seed breeding companies to develop and release a non hybridised variety

into developing countries. One of the traits that is being worked on within their GM regimes is a gene which would withstand longer periods of drought.

11. **Machinery optimisation:** A simple example of machine capacity improvement is occurring on most farms that are growing grain maize. The combine harvester is able to complete almost another season of work if maize harvest occurs between October and December. As I found out while interviewing, some growers - for example in central France - see this as the *norm*, and so their costs are already shared across a wide harvest window, from oilseeds in July to October for maize. The same is true for drying equipment, chaser bins, and even spraying comes into a window of its own.
12. **Risk:** There is a measure of risk reduction with a crop which uses lower input costs- particularly where the bulk of variable inputs are on pre-harvest costs. As the highest cost of a wheat/cereal crop will be fertiliser/chemical inputs and the highest for maize is seed/drying charges, so the proportion of costs which are 'post-harvest' are final yield-related. In areas where flood/drought/wind damage/lodging are a real risk, then there is a real comfort gained from the fact that a major yield reduction in maize would see savings on the drying which are not insignificant.
13. **Opportunities not limited to maize:** There are a number of other potential cost reductions for grain maize (although some relate to mainstream cereals too, to a different extent) such as drying technology. Many continuous-flow and batch hot-air dryers are set up at less than optimal efficiency, and many are using antiquated control technology. Under UK conditions wheat does not have to be dried every year, so investment in drying facilities is often overlooked when a capital expenditure budget is drawn up. Other technology has seen faster uptake when the equipment has more regular use. Even the harvester sees more guaranteed use every season, and so GPS, controlled traffic and yield monitoring are commonplace. As drying costs increase due to fuel price increases, then it is likely that heavy fuel users such as the grain dryer will see economically driven capital expenditure. In a grain maize regime, where the dryer is much more intensive, then fuel economy is paramount.

The costs of running a diesel fired burner are documented by others, including Nix (Nix, 2010) with fuel usage running at around 1.25litres/tonne/% removed. Work has been done to improve the quality of the drying to retain colour of the grain, relating to the number of passes through a dryer, and the 'dwell' time or equalisation period between passes. During interviews with UK dryer operators, up to two days has been mentioned, but work done in Thailand (*Prachayawarakorn, 2004*) suggests that an optimum temperature of 120C down to 23% moisture content (% m.c.) and then as little as a 40 minute tempering period are best for overall grain quality.

- The fuel type used is worthy of note as most dryers are using a relatively high grade of fuel source (diesel or gas), both of which are likely to rise in price against low grade fuels in the future. The suggestion is that low grade fuels such as wood and forestry waste are competing with 'inconvenient'/bulky fuels such as coal which will be unlikely to fuel high grade users such as transport or aviation. Note that electricity is rarely used now as a heat source as it has been priced out of range by high grade users such as computing and telecommunications. However, microwave driers are commercially available abroad, but more work needs to be done on their performance on a commercial scale. In particular, the Russian Federation has done a great deal of work on this method of grain drying. There are, however, suggestions that with large commercial use of microwave heater banks, that some degradation of the quality is found in the grain. The vitamin Thiamin is thought to be reduced in this way. The reduction of energy required to remove each 1% of moisture would be of great interest to the arable industry.

6.4. Threats to maize as a future candidate in the rotation

1. **Pests & diseases.** e.g. *diabrotica* sp (European corn root borer) was found in the UK in 2003. Initial findings were based around the main international airports, with the implication that aircraft undercarriages were carrying foreign infectious materials.

(<http://www.fera.defra.gov.uk/plants/publications/documents/factsheets/diabspecies.pdf>) (DEFRA, FERA, 2004)

Eyespot prevalence is likely to build up as maize is grown more widely and, although there are chemical methods available to control this, there are also moves to investigate other non chemical means. An ultra-violet light source at early stages of crop growth (where the crop is only 300-500mm tall) has been tried and other more novel techniques are possibilities, such as ultrasound and infrared applications. Some of these techniques may become practical options for this wide-row space crop, as there is an abundance of space to accommodate the equipment between the rows. (Agrios, 2005)

2. **Chemical availability.** As with cereals, there is a strong likelihood that more of the available chemicals will be removed from the permitted lists whilst new active ingredients are slow to join the lists. The Chemical Regulation Directorate of the Health and Safety Executive maintains these regulatory requirements. (<http://www.pesticides.gov.uk/>)
3. **Fertiliser use** is under close scrutiny with losses to the environment a growing concern. The EU has implemented closer nitrogen budgeting and some nations have taken the budgeting to a quarterly level, thus reducing losses, but making it more difficult to apply some waste streams to arable rotations. Future arable rotations will require careful planning to ensure that the nitrogen requirements match the supply of nutrients more closely.
4. **Soil run-off** in an over-winter situation is a potential problem and soil structure is critical for good yields - especially in a continuous maize rotation. Over-winter cover crops are almost certain to require attention. In continental Europe the rules for cover cropping vary widely, and they are in need of some streamlining for fairness. Much work has been done on the continent with oilseed rape, various forage crops, and even a few other oilseed crops, some of which could come to maturity before planting maize again in a short growing season situation. Generally, soil improvement and nutrient locking are the main purposes of these over-wintered crops.

7.00 Attempts to quantify potential future yield improvements

7.1 Methodology

The degree to which the future of maize holds the key to profitability relies on the fact that it is of subtropical origin. Biology lessons of yore remind us that maize originated in Mexico. It is a member of the crop groups known as 'C4', whereas normal grass species are of 'C3' type. There is a good description of the way in which C4 and C3 pathway crops work by Dr Colin Osborne published by the Royal Society (*Osborne, 2010*) and Dr Stephen Saupé (*Saupé, 2009*), and a resume can be found in Appendix D. The selection of C4 crops during a fall in global CO₂ may have led to C4 crops being able to yield more. (*Reddy, et al., 2000*).

The basic summary of the differences between a C4 crop and C3 is that with the former a 'shortcut' is taken in the part of the cycle that assimilates CO₂ into carbohydrates, especially under higher temperatures.

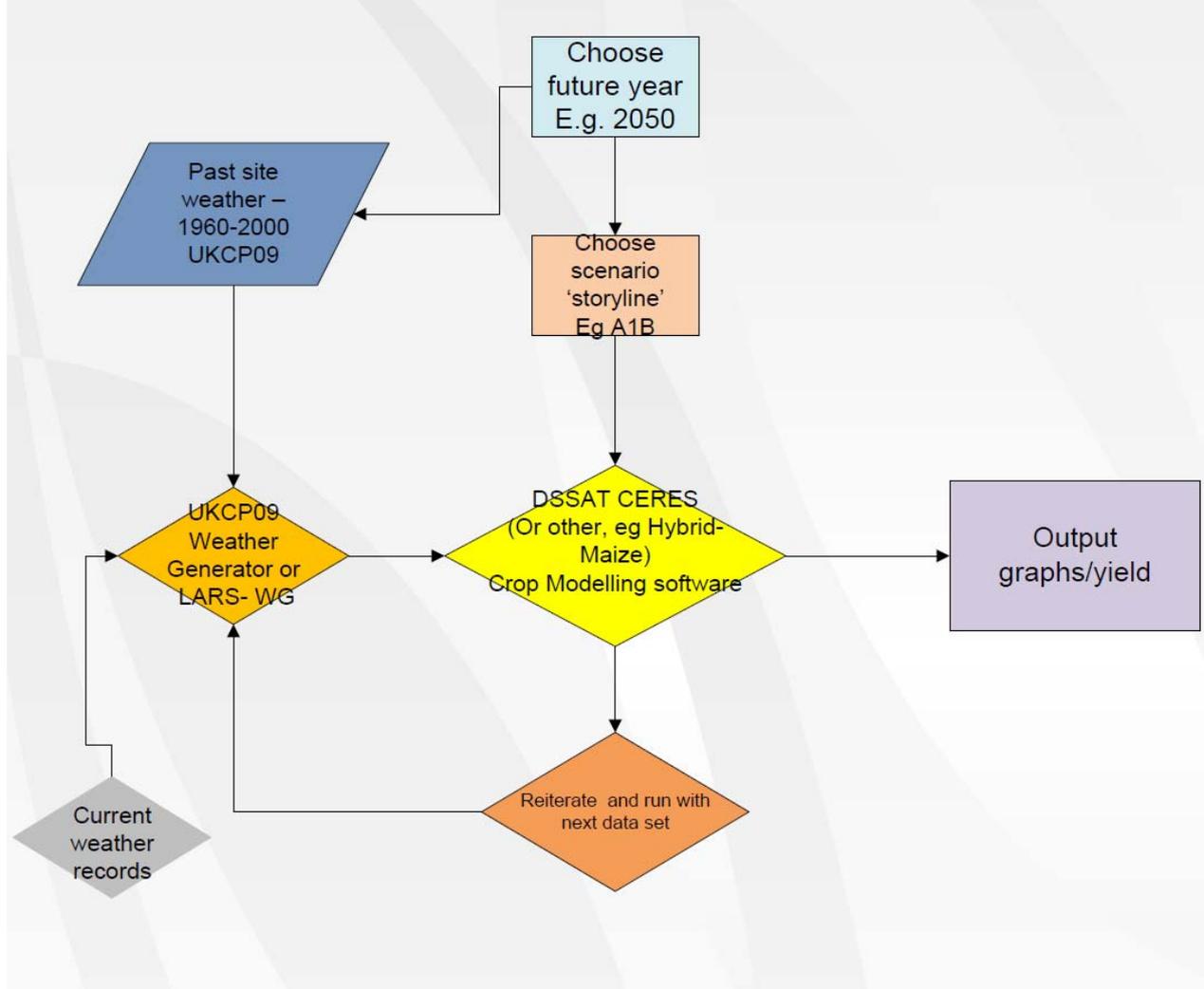
It therefore follows that, to satisfy the queries with this crop, some further investigation is warranted. Others have looked at this in continental Europe to find a yield response including Joost (*Joost W, 1998*) and within UK (*Fitt, et al., 2009*)

When a farmer decides whether to grow a crop, he considers the margin. The main driver of the margin in maize or wheat will be the yield per area.

This chapter deals with the main element of the profitability - the future capability of maize to absorb more of any temperature increase and convert it to yield.

A range of techniques are employed within a framework to attempt to grow a theoretical crop of maize under simulated weather conditions for year 2050. The diagram on the next page shows how several different packages were used to calculate a yield:

Methodology of yield forecasting under climate change



Source: Alistair House 2010

7.2 Techniques used to produce estimates of yield/margin

(a) DSSAT/ ICASA 'CERES' for maize

For a number of years, the International Consortium for Agricultural Systems Applications (ICASA), based in Hawaii, has been coordinating the management of the 'CERES' program, as well as updating it. The program is open for all parties to use, although not all of the code is freely available. There are however, several licensed variations of it in use, one of which is used in Hungary, called 4M and adapted by Nandor Fodor. (Fodor, 2006). CERES uses an enormous volume of previous data and regresses it to a curve of yield with the various inputs such as soil type, fertiliser, daily weather, variety, CO₂, etc.

These versions requires daily weather information - and for testing purposes it is possible to test the validity of the program by assessing yields in arrears, as well as current weather to predict a current year. Of course the main purpose in this project, though, is to assess a future year.

(b)'Hybrid-Maize'

A version based on similar principles as CERES, this program has been developed by the University of Nebraska-Lincoln, by Yang, Dobermann, Cassman, Walters. (Yang, et al., 2006) This program has a more basic 'front-end' and is less versatile, but nonetheless useful for comparison. The input page is below:

The screenshot displays the 'Hybrid-Maize' software interface. The window title is 'Hybrid-Maize' and it features a menu bar with 'Settings', 'Save Results', 'Print', 'Utilities', and 'Help'. The main interface is divided into several sections: 'General Input', 'Water', 'Nitrogen', and 'Soil'. The 'General Input' section includes fields for 'Weather file...', 'Simulation mode' (Current season prediction, Single year), 'Start from' (Emergence, Planting), 'Seed brand' (Pioneer), 'Maturity' (GDD50F, Date, Relative maturity), and 'Population (x1000/acre)'. The 'Water' section has options for 'Optimal' and 'Rainfed / Irrigated' irrigation, with an 'Irrigation schedule' table. The 'Nitrogen' section includes 'Optimal' and 'Last season residues incorporation' options. The 'Soil' section includes 'Max rooting depth (inch)' and a table for 'Top-soil' and 'Sub-soil' properties like Texture, Initial moisture status, and Bulk density. A 'Run...' button is located in the bottom right corner. The Windows taskbar at the bottom shows the date as 19/11/2010 and the time as 15:16.

Hybrid-maize input front page

(c) A summary of the differences between the DSSAT-CERES and HYBRID-MAIZE is produced in a report by Yang et al (*Yang, et al., 2003*).

Unfortunately Hybrid-Maize does not have a cold tolerant variety within its standard data set, and so it will not run a simulation without first changing the crop data.

CO₂ is not considered in Hybrid-Maize, whereas Ceres does take it into account. Most C4 crops are saturated by current CO₂ concentrations, (but lacking in temperature) and so they do not benefit from increased CO₂ as does the C3 crop, (where approximately a 30% increase in assimilation results from a doubling of CO₂). Ceres is written to work on a wide ranging set of crops and so the CO₂ element is built in.

7.3 Weather generators

UKCP09 (<http://ukclimateprojections.defra.gov.uk/content/view/728/690/>)

The Hadley Centre, Oxfordshire and the Meteorological Office, (funded by DEFRA), host enormous computer capacity to estimate future climate scenarios (HadCM3). The HadCM3 (and other climate models) predict climate. One chooses one of the various scenarios and a future time period to examine the predicted climate of. A weather generator produces daily weather series (e.g. of the variables mentioned), which are statistically consistent with the chosen climate predictions. A number of these must be generated for the time period in question to gain a representative set of simulated daily weather. These are then suitable for input into the crop models.

There are a series of other Weather Generators and they have gained in complexity over the past decade as computer power has become more accessible, ranging from monthly data sets to daily, and even hourly outputs. The accurate recording of past weather is a prerequisite of any forecasting tool, and of course it was impossible to know in advance that the data would have been required in the future, so data is limited to that from around the 1960s for most data types.

For accurate calculation of future scenarios, it is necessary to take multiple runs of the year in question, get a predicted yield, and average these. This is vital, otherwise the averaging process can 'mask' the outcomes. (For example, a forecasted weather pattern which may be more variable than currently seen, might have weather in May ranging from freezing to + 25C, the weighted average might be 12C. Current temperatures might be 10C, but in the wider ranging scenario, neither freezing nor 25C would be good for yields of maize, and crops failures might be more commonplace with even with moderately higher temperatures.)

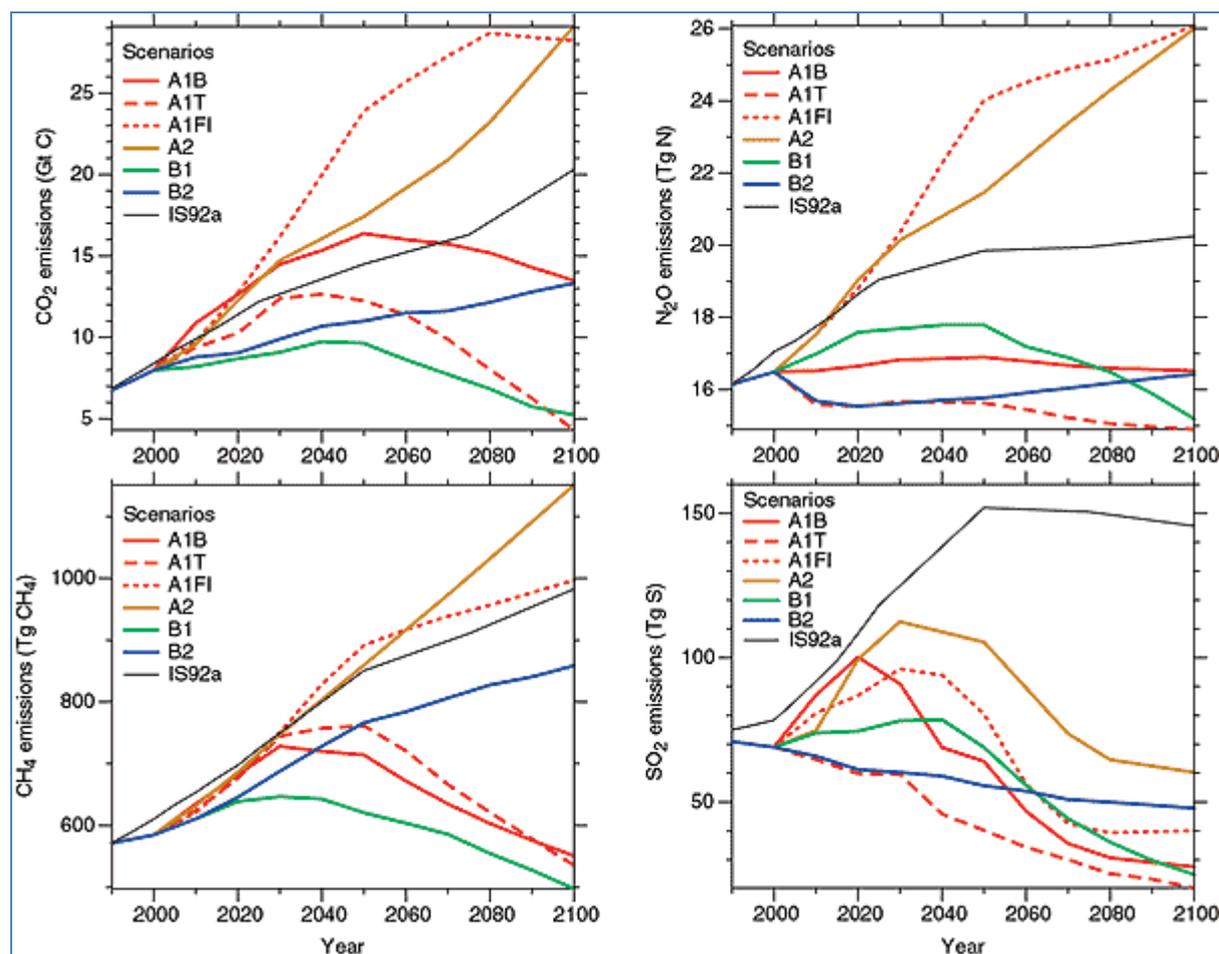
The UKCP09 User Interface is the access point for users to gain access to the Met Office computers. Access is currently free, (but data from the Meteorological Office for past years is chargeable).

One of the earliest Weather Generators in the UK was **LARS-WG** (which was originally produced at the Long Ashton Research Station, Somerset). This has since been closed. Rothamsted Research Institute now covers this work and is developing a more up to date version. (Semenov, 2010).

7.4 IPCC scenarios

The range of confidence levels for future climate is described by the Intergovernmental Panel on Climate Change (IPCC). Special Report on Emissions Scenarios (SRES) (*Nakicenovic; Swart, 2000*). Whilst it remains the definitive article, it was recalculated in 2004, and known as SRES4.

Below is an extract from the IPCC chart of the various outcomes, where the mostly 'likely' future scenario is called 'A1B'. (see appendix A for the full description.)



Source: IPCC SRES4

2007

(CO₂ concentration for the baseline scenario, 1960–1990, is 334 ppm]

The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES) - IPCC

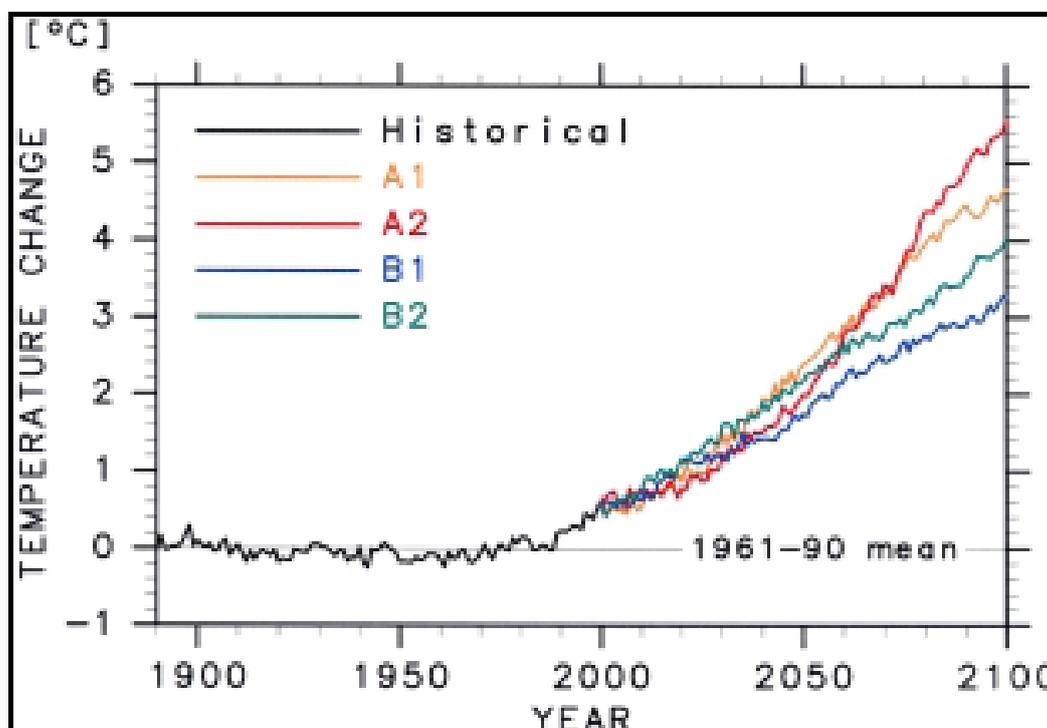
A1. *The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.*

Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where 'balanced' is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

IPCC-2007

The 'storyline' themes then translate into fossil fuel use and emissions into a predicted temperature rise - as in the next figure.



Temporal evolutions of global and annual mean surface air temperature change with respect to the 1961–90 average (13.7°C) .Source: IPCC SRES4 2007

In this report, A1B is used, but surprisingly this also shows a predicted increase in CO₂ of from 334 to 541ppb by 2050. This will have the effect of increasing crop yields in certain areas. Temperature is estimated to rise by approx 2.5°C by 2050 and by 4.6°C by 2100.

Excel® – LINEST- Linear regression package

This is available within the Microsoft Office package, and takes one or more sets of data to find a common formula. It was used in this instance to find the expected trends of margin, (given the yields produced in Ceres) that can be formulated into a gross margin estimate that a farmer might expect to see in his cropping plan, in a given future year.

Yield data from the family farm in Somerset in 2009 has been plotted against planting date, as well variety, but only confirms that earlier planting dates do result in higher yields.

7.5 Caveats to the calculations

The above calculations all produce their own mathematical likelihoods and inaccuracies, which can compound into a very inaccurate output. Some critics would comment that with such a large range of potential pitfalls, there is little point in the calculations. With further monitoring of current weather, and better understanding of the feedback loops that are present in the world weather system, greater confidence can be held in the output.

Baseline:- The data for the current year, used as a 'status quo', has been taken as an average of 2000-2009, and being a reasonably narrow window for a base can be useful statistically. However, the baseline for the data for the weather generator is taken as 1961-1990. The results are perhaps indicative rather than definitive.

The absorption of CO₂ in maize is less important than in wheat, but the wheat absorption of CO₂ is handled by DSSAT CERES.

The programs used for these maize calculations are different from those which were used to calculate the wheat and oilseed rape results. This could be a problem but the programs both use similar methods and data manipulation methods. Further work could confirm if the results are significantly different.

It was a concern that any programs that have regressed yield data over the past 20-30 years will have had crop yields that may have benefited from changes in CO₂ levels during that period, and so could have mildly affected the results. This means that 'baseline' calculations have to be factored in.

7.6 Results

The headline figure for increase in yield for maize somewhere in central UK is something in the order of 12-20%. Wheat over the same period benefits by up to 30%. The main effect that is being investigated is the vulnerability of wheat to high temperatures at flowering, which could reduce any benefits by introducing an increased likelihood of crop failure due to high temperatures at flowering - see (*Semenov, 2009*). Oilseed rape ranges from a benefit of +15% in Scotland to a potential yield reduction of -50% in southern England. (*Butterworth, et al., 2009*). These calculations were done with 2050HI scenario data (this is the future scenario that expects temperatures to rise more steeply), so they are not directly comparable.

The effect that this has on gross margin is harder to quantify, since the risk element is more intangible. However, the risks associated with maize (e.g. late frosts, drought), reduce, and so its margin is improved. More evaluation will be required with multiple years and a range of hybrids to ascertain what will be a more accurate result for each region of the country. Different hybrids may also produce differing results. Reiterating with earlier drilling dates may also be necessary as different temperature scenarios are evaluated.

A 20% yield increase in grain maize has the effect of improving net margin by 47% (taking 'grain maize' margin from column 1 of Appendix B, equates to £232/ha). Conversely, a recent crude oil price rise of \$60 per barrel transferred into a fertiliser (34.5AN) price increase of around £200/tonne. This could have had the effect of reducing margins of wheat and maize £122 and £9 respectively- with drying costs accounted for.

It is accepted that the element of margin will be a much more complicated equation if we push forward to 2050, with a great deal of conjecture. It would certainly be a worthwhile exercise to establish what relationships exist between the various inputs.

8. Conclusions

- The overwhelming evidence is in favour of climate change being here to stay.
- It is also likely, although still disputed, that this change is the result of human activity.
- It appears that the demands on agriculture to deliver food, feed and fibre will increase - possibly faster than its ability to meet them.
- It is likely that the weather patterns required for maize will be increasingly encountered in the future, and the same temperature fluctuations could hinder the progress of mainstream cereals.
- Political influence will have an impact on the technology available to farmers. This could be in the form of an early release of the ban on GM, or the continued restriction of available chemicals. It could be in the form of partial removal of subsidies, or in 'green-box' equivalents which will encourage a broad biodiversity of wildlife in the farmer's 'park-keeping' role. What is certain is that there will be increased conflict between the interests of the voting public and the requirements that are put before the producers by the scientists predicting a worsening supply/demand imbalance.
- With most cereals there is some cost involved for drying. With maize however, one of the more significant variable costs is associated with drying. The largest portion of that cost is fuel. Currently most dryers are running on fossil based fuels and there is an opportunity to switch to a lower grade fuel - at least for base load of drying - see Recommendations on next page.

9. Recommendations

- The same opportunities for seed breeding should be afforded to maize as for other mainstream cereals to ensure that hybrids are ready for any potential increase in area.
- Maize may be able to meet public demands for reduced chemical inputs by the use of other technologies which can only work with wide row spacing.
- A different government assistance package would enable farmers to afford the perceived risk of a relatively less well known crop. A crop revenue guarantee program on the same basis as the US system would enable farmers to effectively hedge against a guaranteed price for their crop (currently 80% in the USA based “Crop Revenue Coverage” scheme). This helps with cash flow and in turn gives confidence to banks in an industry which struggles with cash flow shortage. It guarantees the yield and the price per tonne, so it differs from a “Multi-Peril Crop Insurance” (MCPI) which will only pay out on a crop loss. Governments often help with the cost of these packages, but they are not seen as an ‘intervention’ method.
- Capital investment is required in the industry - but it is probably required regardless of which crop is being grown. Drying facilities, irrigation, planting and harvesting technology are all in need of an overhaul if agriculture is to keep up with the demands on it.
- Help is needed in near and far market research to catch up on the years since agricultural research budgets were cut so heavily.
- Continued education will be required for operators and growers of a crop who have little ‘experiential’ knowledge of it. It is apparent that, since the abolition of ADAS in British Agriculture, there is a widening gap between the value of research being commissioned and the extension work to get it applied in the field
- Modelling (to a greater degree of accuracy than in this report!) would help to gauge the extent to which the recommendations listed above might be warranted.
- Much of the fuel used for drying is currently diesel and these dryers could be quite easily converted to utilise lower grade fuels. The ‘road tax’ element of diesel in 2010 is approximately 11 pence/litre, or 21%. It seems incongruous that this road tax is being paid for a fuel that is not related to road transport - when in fact it reduces the amount of road traffic. A well rounded case needs to be put before government to allow rebates to be drawn on these duties. Beyond this, there is a good case for using either combined heat and power in drying plants to gain efficiencies, or better still, a move towards developing biomass burners for carbon benefit. Biomass’ lack of convenience is largely offset by the benefits of using a low grade bulky fuel near to where it is burned. Again government assistance/direction will be required. Other nations are receiving subsidies, whereas the UK is being taxed on drying.

10. The Future - as I see it

Whilst each of the above recommendations requires action, most need to be put in the hands of researchers - but funding would need to be authorised by policy makers.

To put the 'story' out to the farmers who are open to the idea of a new crop, I envisage a series of talks and presentations.

Legislation changes will govern the reaction by growers and industry.

Public reaction to GMOs or chemicals (seen recently with animal cloning) can be altered by government, marketeers, supermarkets, or sometimes a fear of cross infection from another foodstuff (e.g. 'swine flu' hitting pork consumption). A specialist growers' group under the wing of the MGA might be useful to form a consensus of opinion and disseminate useful advice. This will be important as the crop moves from niche to mainstream cereal, to help the feed industry cope with sourcing relevant quality of product.

A move to encourage the return to an equivalent to ADAS needs further investigation, as we are losing out to foreign competition in what is perhaps already an indigenous crop.

On my travels abroad I found a good uptake of technology, a better situation than I found in the UK. I feel that in most cases the UK situation would be improved by a 'free-to-user' extension service.

***For further information please feel free to contact me at:
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Terms and Abbreviations

ADAS	Agricultural Development Advisory Service (of the ex Ministry of Agriculture)
CAP	Common Agricultural Policy (of the European Union, EU)
CC	Climate Change
CO ₂	Carbon Dioxide
DEFRA	Department for the Environment Food and Rural Affairs (UK current)
DOY	Day of Year (a decimal way of handling dates- eg May 1 st = DOY 121)
ECPA	European Conference on Precision Agriculture
EFITA	European Federation for Information Technology in Agriculture, Food and the Environment
EPCLF	European Conference on Precision Livestock Farming
EU (27)	European Union of 27 nations
GM	Genetic Modification
HadCM3	Hadley Centre Model 3 of the coupled atmosphere-ocean general circulation model (AOGCM)
IPCC	Intergovernmental Panel on Climate Change
INTA	Instituto Nacional de Tecnologia Agropecuaria, (Argentina)
JIAC	Joint International Agricultural Conference (biennial), 2009, 2011 etc.
MGA	Maize Growers Association, UK (www.maizegrowersassociation.co.uk)
NIAB	National Institute of Agricultural Botany
NO _x	The category of all Nitrogenous Oxides/ [e.g. Nitrites/Nitrates]
NVZ	Nitrate Vulnerable Zones
ppb	parts per billion
ppl	Pence per litre
SRES	Special Report on Emissions Scenarios (IPCC)
WG	Weather Generator

APPENDIX A

Taken from The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES4) 2007

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

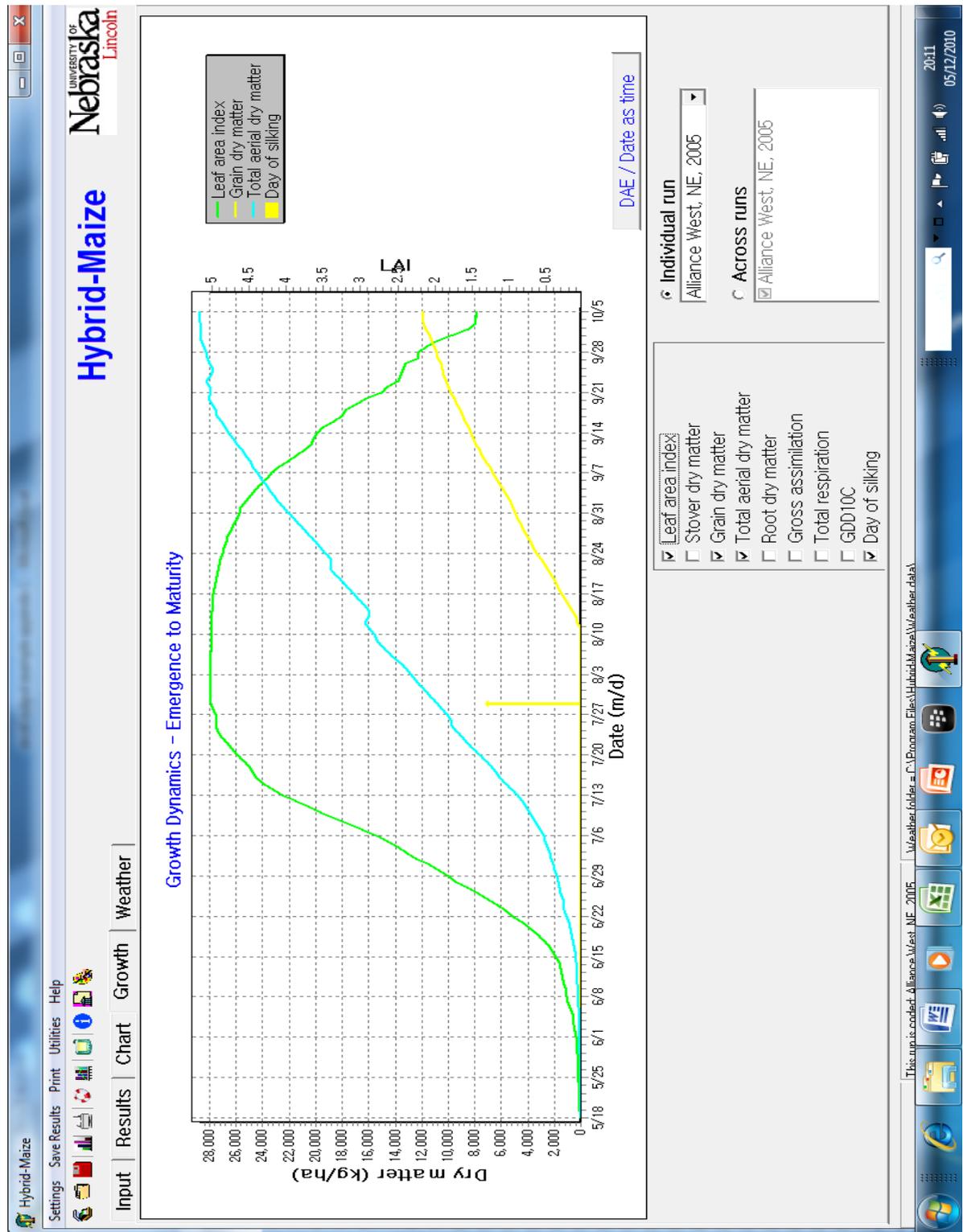
APPENDIX B

GROSS MARGIN DATA courtesy of Maize Growers Association estimates for production season 2010

	Grain Maize	Winter Wheat	Spring OSR	Winter OSR	Winter Oats
Output					
Yield (tonnes/ha @ 15%)	8	9	2	4	7
£/tonne (net of drying)	145	130	280	280	135
Total Output	1160	1170	560	980	945
Establishment Costs (£/ha)					
Ploughing	50	50	50	50	50
Cultivations	42	42	42	42	42
Sowing	42	33	33	33	33
Seed	100	45	45	45	45
Fertiliser* (breakdown at bottom of chart)	182	172	110	173	168
Sprays	62	125	70	105	75
Total	478	467	350	448	413
Contractor Costs (£/ha)					
Fertiliser Applications	20	30	20	30	20
Spray applications	11	40	30	30	30
Harvest	90	90	90	90	90
Total	121	160	140	150	140
Total Annual Cost (£/ha)	599	627	490	598	553
Net Margin (£/ha)	561	543	70	382	392
*Fertiliser Applications per ha.	120kg N 60 kg P 120 kg K	180 kg N 60 kg P 35 kg K	120 kg N 30 kg P 25 kg K	190 kg N 50 kg P 35 kg K	130 kg N 55 kg P 90 kg K
*Fertiliser Costs per unit	N= 65p/kg.		P = 59p/kg	K = 57p/kg	
*Fertiliser Cost £/ha.	182	172	110	173	168

Source: Briony Burge 2010 (*Burge, 2010*) amended

APPENDIX C



Hybrid-Maize Output chart showing Leaf Area Index (LAI), Grain dry-matter (T/Ha), and silking date. (Position, Alliance NE USA)

(Growing day degrees (GDD) are set at all temperatures above 10C.) Source: Hybrid-Maize software

APPENDIX D

A description of the main differences between C3 and C4 plant photosynthetic routes.

C3 plants, accounting for more than 95% of earth's plant species, use rubisco to make a three-carbon compound as the first stable product of carbon fixation. C3 plants flourish in cool, wet, and cloudy climates, where light levels may be low, because the metabolic pathway is more energy efficient, and if water is plentiful, the stomata can stay open and let in more carbon dioxide. However, carbon losses through photorespiration are high.

C4 plants possess biochemical and anatomical mechanisms to raise the intercellular carbon dioxide concentration at the site of fixation, and this reduces, and sometimes eliminates, carbon losses by photorespiration. C4 plants, which inhabit hot, dry environments, have very high water-use efficiency, so that there can be up to twice as much photosynthesis per gram of water as in C3 plants, but C4 metabolism is inefficient in shady or cool environments.

Less than 1% of earth's plant species can be classified as C4.

Source: The Oxford Dictionary of Geography
www.oxfordreference.com

APPENDIX E : typical farm margins in Pergamino region (Argentina) for 2009

Note 5th column is double cropping wheat and soybeans. (SBS = soybeans, BLY=Barley).

Over 10% of the output is freight cost.

AVERAGE PRODUCTION COST STRUCTURE						
Season 09/10						
LOCATION: PERGAMINO						
REGION: North BSAS PROV						
PRODUCTS	SBS 1RST	SBS 2ND	WHEAT	CORN	WHT-SBS2	BLY
Average yield	mt/hs	2.50	4.00	9.00		4.20
FAS VALUE	u\$/s/mt	220.00	145.00	113.00		130.00
FARMER GROSS INCOME	u\$/s/hectare	770.00	580.00	1017.00	1130.00	546.00
PRODUCTION COST						
land rent (mt sbs /ha)	0.00	0.00	0.00	0.00	0.00	0.00
labour		23.00	23.00	23.00	23.00	23.00
seed		35.20	35.20	36.00	100.00	38.00
chemicals & application		75.00	65.00	45.00	38.00	52.00
ferts. & application		27.00	0.00	137.75	127.75	137.75
harvest		53.90	38.50	40.60	71.19	38.22
freights		70.00	50.00	80.00	180.00	37.80
domestic trade ^{3% avg. 100.00}		61.60	44.00	46.40	91.53	43.68
financing (6 months int.rate)	12%	19.22	14.78	29.01	34.65	30.09
TOTAL COST /HS	u\$/s/hs	364.92	270.48	437.76	666.12	400.54
NET FARMER INCOME B/TAX	u\$/s/hs	405.08	142.24	350.88	421.76	145.46
Overhead costs	u\$/s/hs	100.00	100.00	100.00	100.00	100.00
NET EARNINGS B/TAX	u\$/s/hs	305.08	42.24	250.88	321.76	45.46
Relation Total Cost/ Net farmer incomes		1.11	0.32	0.53	0.60	0.36

Source: Cargill Argentina 2009

APPENDIX F

DSSAT CERES output showing Leaf Area Index (LAI) of three long-season varieties-(which do not reach flowering due to conditions being too cold)

