Nuffield Farming Scholarships Trust

The Harold Cowburn Award

The search for sustainable agriculture

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October 2011

The Nuffield Farming Scholarships Trust is indebted to the late Harold Cowburn for his support of this Award

To Claire, Ffion

& Rowan

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1.0. FOREWORD

Figure 1: the author on a wind farm in Palm Springs, California

As a child growing up in North Yorkshire I had two choices, the sea, or the land, my father was a ships chandler on the Tees and the Tyne, that introduced me to boats, ships and heavy equipment. At home though we were surrounded by farms and many of my friends were from farming families, by 13 I had established an egg and turkey business and had begun working on local farms often skipping school to do so. It was through those school years that farming really got under my skin, it become the start of a lifelong relationship with an industry that also become my passion.

From school I went to the bright lights of Newcastle eventually coming away with an Agriculture degree and a Geordie who would become the mother of my children. I worked in a range of farm management positions throughout the North of England and Denmark before moving to a farm business consultant role in central Scotland, this was the classic in at the deep end job, but it helped me hone the skills I would need for my role as the farm manager at Harper Adams University College, a job which has kept me excited with fresh projects and challenges for 12 years now.

When I set off on my Nuffield study I began with the title 'The search for green opportunities'. To me and most of the industry in late 2009 the contribution of agriculture to the sustainability debate seemed to centre on greenhouse gases from livestock and the drive for renewable energy, both the result of a fixation on climate change alone. My focus rather naively was to seek the next green product, technology or idea of which I could take advantage. What I got instead was a glimpse of the infinite elements that intertwine to create the global farm, and validation that globalisation is real and is changing the face of agriculture, but, in doing so it is bringing forward countless exciting new opportunities. It is for that insight I will always be grateful to the Nuffield Trust and more especially to my sponsor Harold Cowburn who took a leap of faith to support my study.

At an early stage in my study I realised that there was a much larger and more fascinating debate emerging. The industry already had an awareness of some of the elements in that debate, but the conclusions contained in the Foresight report, 'The Future of Food and Farming' were still a surprise to many people. The Chief Scientific Adviser to HM Government who commissioned the report, Professor Sir John Beddington, used it to call for urgent action across the global food system. In a Guardian headline in 2009 he famously described the pressures that the global food system would experience in the next few decades as *"A 'Perfect Storm' of food shortages, scarce water and insufficient energy resources that threaten to unleash public unrest, cross-border conflicts and mass migration"*. He suggested that this would come to a head in 2030.

It was my increasing realisation of the challenges that humanity will ask agriculture to address that caused me to redefine my study. My search became not just about seeking a green opportunity but about understanding what sustainable agriculture looks like. The first thing of which I was only too aware was what a huge and complicated subject this is. The Foresight report only scratched the surface of the subject despite the contribution of over 400 experts from 35 countries. I wanted to concentrate on some of the main issues we face notably population growth and a diminishing resource base from which to increase production. I also wanted to understand what a sustainable agriculture industry will look like in 20-30 years and it was on that journey that I got one of my biggest surprises: how R & D around the world needs reinventing to deal with some of the challenges of sustainability.

The challenge is of a magnitude beyond comprehension, but it is achievable if it is given the importance it deserves. If we get it right farmers will be the heroes of the story. If we ignore the challenge we risk being the villains; I spent the 80s and 90s watching UK agriculture lurch from one crisis to another and the respect for farmers sink beyond sight. That is not an episode we should revisit.

Nobody embarks on a Nuffield Scholarship lightly and if they do the trauma of the interviews in London probably puts paid to their naivety very quickly. Those who have less choice in the matter are the family and colleagues who fill the void you create. My wife Claire and children Ffion and Rowan especially bore the brunt of what must have looked like a mid-life crisis at times. They provided support through some of the difficult times and laughed with me through the more bizarre ones. Also important were the numerous staff at Harper Adams University College who have filled my shoes while I was away and supported me every step of way. My travels reinforced to me what a world class institution Harper Adams has become.

My Nuffield project revealed an industry full of passionate, innovative, dedicated people often brimming with humanity; farming has a common language which traverses boundaries and culture. The list of those who helped me along the way is huge and to every one of them I am hugely grateful. Invariably there were a number of individuals who went that extra mile and turned out to be critical to the success of a trip.

On one of my first trips through the American Mid-West I focussed on carbon credits and trading mechanisms, carbon sequestration and greenhouse gas mitigation. Of particular help were Dale Enerson of the North Dakota Farmers Union, and Nathan Clark at the Chicago Climate Exchange, a fantastic initiative which has unfortunately now closed through lack of political will in America to commoditise carbon.

China was one of the most challenging of countries to visit but my way was eased considerably with the help of Professor Brian Revell and especially Peter Bloxham who allowed me access to the wealth of contacts he has cultivated while living and working in China.

In California I had the privilege of meeting one of the most fascinating people ever - Robert Hennrikson who apart from being a pioneer in the world of algae has an incredible life story and introduced me to other pioneers like Ben Cloud and Ron Henson in Arizona. At UC Davis in North California Emma Torbert gave up a lot of time to help identify and organise a range of visits, including a very challenging round table brainstorm over the definition of Sustainability. Also in California was Paul Martin of the Western United Dairyman's Association who set up a number of visits to look at renewable power generation on farms across the State.

In Canada I had the opportunity to look at sustainability issues surrounding arable systems and intensive livestock the most striking of which were the dramatic benefits of a shift to zero tillage systems. Canada was one of the most forthcoming of all the countries I visited. Two people, in particular Nuffield Scholar and zero tillage pioneer Jim Halford and University of Manitoba soil researcher Don Flaten set me up for a wonderful few weeks in this incredible country.

One of the most exciting countries I visited was Kenya; it gave me an opportunity to see the issues of rapid population growth that is driving much of the pressure we face as well as the poverty that torments so many parts of the world. There I experienced the incredible hospitality of Henry Wainwright and Louise Labuschangne who not only gave me somewhere to rest my head but also helped to organise some amazing visits.

Conferences were particularly great ways to make contacts and gather high quality information. My thanks must go to Colin Carter of Terrapin, who recognised the value of Nuffield and allowed me to attend the first class future farm conference that he launched in 2011 and I hope will become an annual diary entry.

Without these people and many more too numerous to mention my study would not have been one of the most wonderful things I have ever done. I sincerely thank you all.

Scott Kirby

31st July 2011

2.0 EXECUTIVE SUMMARY

And he gave it for his opinion, "that whoever could make two ears of corn, or two blades of grass, to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together." Jonathan Swift

The world is waking up to the importance of agriculture and its primary role as a food producer. An increasing world population is nothing new.. It has been growing for many years - but finally its impact is at the top of most agendas: no conference, article or sound bite is complete without the inclusion of '9 billion' and '2050'. It was with all of this in mind that I began to define my study. I wanted to understand what the industry will look like in 20 years' time, and how we will feed the 8.3 billion people in 2031.

What I found were many reasons to be excited about the future. The world population will increase but it is doing so at a decelerating rate, to peak at about 10 billion around 2060. That population will be wealthier, fewer people will live in poverty, food demand will increase radically and food prices will rise but this will allow more income to flow into agriculture: we are already seeing the effect of this around the world in the form of investment in agricultural capacity and infrastructure, creating new supplies and efficiencies that previously did not exist. There are risks, not everyone will benefit, which will mean the more vulnerable will need protection but for many the opportunities that will be generated around the world will be beneficial.

Wherever I travelled I realised that there remains much latent potential to increase food supply, though in many cases the barriers to be overcome can be considerable. Many of the regions with the greatest potential also have the greatest problems in terms of political stability, infrastructure, access to investment and technical ability. Where these can be resolved the results could be staggering.

In many of the developed countries the attitude to production is more complicated. The industry is mature and increased output opportunities are relatively modest. The emphasis in these countries is the improvement of resource use efficiency and the delivery of environmental services. This gives me some concern particularly in Europe where we are increasingly becoming vulnerable to food price shocks through growing dependence on food imports, and appears to be unnecessary for a region with such rich agricultural resources. As food production technology advances in Europe increasingly fall behind other parts of the world there is likely to be an ever growing land mass devoted to feeding Europe; this is a 'land grab' by proxy.

Better management of our natural resources could provide many opportunities. Nutrients for example are a major feature of agricultural sustainability. In excess they degrade the environment, and in deficit they demand the extraction of finite earth reserves. Greater emphasis on recapturing nutrients from all sources, not just agriculture, rather than allowing their leakage into the environment could contribute to increased sustainability

Sustainable systems, by their nature, are huge and very complicated and conventional structures do not always fit or guarantee a sustainable approach. One of the most striking conclusions I came to on my travels was how much of the world's agricultural research community is unfit to address this new challenge. It is overly short term and too focussed on individuals and publishing rather than the 'delivery 'of real solutions.

Sustainability also requires a value; agriculture has latent capacity to contribute to climate change mitigation on a much larger scale but, all too often, incentives do not exist to deploy this potential. There are limited examples where measures have been taken such as the subsidisation of renewable energy or the commoditisation of carbon to create a value for sustainability goods. What is required, however, is a different approach to the idea of profit and loss that accounts for the real sustainability of our activities. In 1968 in an eloquent deconstruction of modern economics Robert Kennedy said that 'Gross national product measures everything except that which makes life worthwhile'. This particularly applies to sustainability.

My study covered a vast range of sustainability topics, many more than this report has room to address but throughout there have been common themes emerging, not least the realisation that sustainability is complicated and that it cannot be reduced to the lowest common denominator. True sustainability depends on the effective integration of systems. If we include this concept in more of our planning and strategy we will make more sustainable advances.

3.0 INTRODUCTION

Summary

We passed the point of sustainability in 1976 when mankind's ecological footprint first exceeded the planet's capacity. Today the demands of mankind equate to the resources of 1.35 planets and if all 9 billion people who will exist in 2050 were to achieve a western lifestyle that would equate to 3 planets. Sustainability is now debated front and centre. There is a growing awareness of its importance even if in most cases there is limited understanding of what it means. The consumer is being helped to understand sustainability by the growing involvement of retailers and processors who are increasingly becoming the main drivers of the sustainability agenda.

3.1 THE GATHERING STORM

Around 1976 there was an event of monumental proportions the effects of which resounded around the globe and threaten eventually to cause the collapse of the human race. Yet throughout the 1970s the event did not feature in one press report or news broadcast; for the world it was essentially business as usual. Concorde took its first commercial flight; Harold Wilson resigned as Prime Minister and British and Icelandic warships clashed in the 'Cod Wars'. This perilous event was when humanity passed the point at which its annual ecological footprint matched the Earth's annual 'Bio capacity'. In effect the earth's population reached the point where it was consuming renewable resources faster than the planet's natural systems could regenerate them.

The Global Footprint Network based in California annually tracks the state of global sustainability as an ecological footprint (*Global Footprint Network, 2010).* Since the mid 1970s it has shown that the 'ecological overshoot' has grown relentlessly.

Analysts use units called global hectares (gha) to express the ecological footprint (the demand for natural resources) and the bio capacity (the availability of natural resources) of the planet. A single gha equates to the average world production capacity of 1 ha of

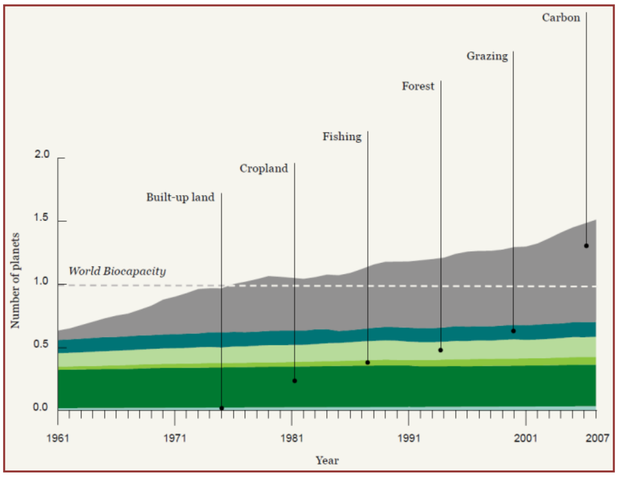

Figure 2: Ecological footprint by component 1961-2007 (World Wildlife Fund, Global Footprint Network & Inst of Zoology, 2010)

land. Every human activity uses biologically productive land and water. In 2007 it was calculated that the earth had a bio capacity of 11.9 billion gha but, with an average ecological footprint of 2.7 gha per person on the planet, we actually need 18 billion gha (*Global Footprint Network, 2010*). Today we are exhausting natural resources at a rate equivalent to 1.5 planets to support current usage rates. If everyone was to live in the same way as most western countries we would need 2.6 planets.

Figure 2 shows the footprints trend and the individual components that make it up. Up until the mid-1970s humanity was using fewer resources than the earth could replace annually. The analogy is we were prudently living within our means, spending the interest from our bank account. By 2007 our prudence had been replaced by a spending spree which has seen us using not just the interest but also the savings. Factor in a population set to increase a further 50% and you really get a sense of the challenge facing mankind.

With such dire projections we might have expected a much more vigorous debate to be raging. It is not unreasonable to suggest that this century's most pressing challenge across the globe will be food security for all. Population growth and increasing resource demand coupled with climate change could lead to global crisis unless a sustainable global agriculture can be created. John Beddington, (*Beddington, 2009)* the UK Government's Chief Scientific Adviser, has famously coined the term 'perfect storm' to describe the crisis that will result from food shortages and water and energy resource limitations. He believes that this threatens to unleash "public unrest, cross-border conflicts and mass migration" and suggests this will come to a head in 2030. His assertions were tested earlier this year when a Foresight report that he commissioned on The 'Future of Food and Farming' (*Foresight, 2011*) was published. The report was the culmination of a two year study involving 400 experts from 35 countries. It was the first modern study to examine the myriad of disciplines that make up the global farming system. The report demonstrates the need to think big whenever we examine the sustainability of any system. Sustainability is not a single factor but depends on complex biological, economic, social and political interactions. The report emphasized that changes need to be made by agriculture to ensure that the need to increase food production is not achieved at the expense of sustainability. The report suggested that incentives need to be provided to encourage agriculture to address issues such as malnutrition, inefficient resource utilisation and food wastage. It has been suggested in many quarters that there is an urgent need to put in place some difficult policy decisions and it has been said that change can be nothing less than the redesign of the entire global food system if sustainability is to come to the fore. This would require a new, concerted and immediate international effort.

3.2 THE SUSTAINABILITY HEIST

In a hotel room in downtown Chicago I opened the minibar to find something fitting to accompany the genuine Chicago pizza that I had just picked up from Lou Malnati's pizzeria. I expected a cold Bud but instead found 'Fiji Water'. It certainly looked inviting decorated with tropical rainforest flowers and at 15 times the price I was getting for my milk back home it had to be pretty fabulous stuff. But it was not the price that really gripped me, rather the claim on the bottle that I could enjoy the water in the knowledge that it was carbon negative, imagine that, the more I drank the smaller the global warming problem would become. If I could get enough friends drinking it we could save a whole ice cap. I was excited, I forgot about my pizza and Googled the company. There was a whole web page devoted to the company's 'sustainable practices'. They were using the most 'responsible' plastic, the most efficient ocean transport, the most energy efficient equipment in the factory and were recycling 95% of their waste. Was this 'sustainability' and, if so, can it in any shape or form make sense to take water from an island in the South Pacific Ocean, place it in plastic bottles and ship it half way round the world to a hotel room in Chicago that had views across Lake Michigan the sixth largest freshwater lake in the world? The water from the bathroom tap proved to be just fine with my pizza.

Figure 3: Carbon negative Fiji water

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs "*
>
> The Brundtland Commission 1987.

And there lies the problem with the word 'sustainability'. It has been hijacked to describe everything from travel to tuna. It has become a big word with little meaning through overuse and misuse by business, politicians, academia and the media alike. It is such an in-vogue topic that everyone wants to be associated with it but misuse is made easy by the lack of a universally agreed definition. The difficulty in agreeing an accepted definition comes from the fact it is a complicated notion made up of numerous interwoven and complex strands and issues. In simple terms these are environmental, economic and social issues, but each is made up of many more factors.

The most widely accepted definition of sustainability was arrived at by the Brundtland Commission of the United Nations General Assembly in 1987. The Commission stated in their 'Our Common Future Report' (*Bruntland Commission, 1987*) that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The definition was suitably vague and did not provide any instruction on how to apply it. Nonetheless it is frequently used, perhaps not surprising in a world where the market reigns and consumers increasingly demand corporate environmental and social responsibility.

We are faced with a puzzle: should we follow the example of the term 'organic' which was just a word until specific standards and certification were put in place, or is there a need to regulate now the use of the word sustainable. Even if it was regulated could this be achieved globally across multiple areas of application? I cannot help thinking whether it really matters what 'sustainability' actually is, because a debate has been ignited which has focused our attention on not what it is but on the lack of it, particularly in our modern food and farming system. If we need anything now maybe it is a word to describe food production that sustains.

3.3 DEFINING SUSTAINABLE AGRICULTURE

You do not go hunting unless you know your quarry, and so it was with my study, to search for sustainable agriculture I needed to understand what it should look like. Throughout my travels I frequently asked people and organisations for their definition of sustainable agriculture. In the main I got fumbled responses or referrals to detailed corporate statements, a selection of which appear in case study 1. What was clear is that there are no shortages of systems that claim to be sustainable and as more people sign up to the notion of sustainable agriculture the number of definitions keeps multiplying. Few definitions would stand up to rigorous scrutiny often because so many insist on ruling out certain technologies or practices on ideological grounds. Even fewer are based on quantifiable justification.

Nevertheless if you strip away the self-interest agendas there are strong themes running through most understandings of what sustainable agriculture should be. To get to a definition we need to consider the basics of what it is we need from sustainable agriculture.

CASE STUDY 1: A DEFINITION COLLECTION: 'SUSTAINABLE AGRICULTURE'

'Sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term contribute to:

- Satisfy human food and fibre needs;
- Enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- Make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- Sustain the economic viability of farm operations: and
- Enhance the quality of life for farmers and society as a whole.

USDA definition, (*Food, Agriculture, Conservation and Trade Act of 1990 (FACTA)*)

The key principles for sustainability are to:

- Integrate biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation and parasitism into food production processes
- Minimise the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers
- Make productive use of the knowledge and skills of farmers, thus improving their self-reliance and substituting human capital for costly external inputs, and
- Make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest and credit management.

Professor Jules Pretty, University of Essex (*Pretty, 2008*)

Sustainable agriculture is farming that lasts.

Bar room discussion, Swift Current, Saskatchewan

The Californian wine industry defined sustainable winegrowing as "growing and winemaking practices that are sensitive to the environment (environmentally sound), responsible to the needs and interests of society-at-large (socially equitable), and are economically feasible to implement and maintain (economically feasible)". This definition is often referred to as the three "E's" of sustainability and is the one used by Lodi growers and LWC's sustainable winegrowing program.

Lodi Winegrowers Definition, Lodi, California (*Lodi winegrape commission, 2009)*

Figure 4: Lodi Wine grape Commission Visitor Centre, Lodi, Northern California

CASE STUDY 1: A DEFINITION COLLECTION: 'SUSTAINABLE AGRICULTURE' contd.

Lacking a specific time horizon, we cannot prove through empirical studies that one approach to agriculture is sustainable or that another is not. It would quite literally take forever to collect the data for such a study. A sustainable agriculture logically must be ecologically sound, economically viable, and socially responsible. Furthermore, these three dimensions, insofar as they relate to sustainability, are inseparable. All three are essential, and thus are all equally critical. **John E Ikerd**, *(Ikerd, 2008)*

Only the family farm system of agricultural production can be truly sustainable. Sustainable agriculture integrates three main goals – environmental health, economic profitability and viability, and social and economic equity. We believe that farmers engaged in sustainable agriculture set out to protect the land, improve the quality of life and enhance the communities in which they live. **North Dakota Farmers Union**, (North Dakota Farmers Union, 2010)

Sustainable agriculture is a productive, competitive and efficient way to produce agricultural products, while at the same time protecting and improving the natural environment and socio-economic conditions of local communities.

This embodies the following principles:

- Provide the base for ensured food safety by producing quality agricultural products and by supporting innovations to improve their quality and safety.
- Secure adequate food supplies to meet the current and future food demand, by producing healthy crops and animals, by increasing efficiency and by keeping resource and external input requirements as low as possible.
- Protect and possibly improve the natural environment and resources, by minimizing any negative effects from agricultural activities on soil, water, air and biodiversity, by optimizing the use of renewable resources and caring for animal welfare.
- Improve the socio-economic conditions of local communities, by supporting economically viable and responsible farming systems.

Sustainable Agriculture Initiative, (*SAI Platform*)

When Food Alliance talks about "sustainable agriculture, " we mean the ability to produce safe, healthy, delicious, and affordable food to meet diverse needs without degrading agricultural lands, the quality of life in our communities, or the resiliency of the broader ecosystems on which we all depend. Its guiding principles are:

- Protecting and conserving water resources.
- Protecting and enhancing soil resources.
- Reducing the environmental and health impacts of pesticides with integrated pest management.
- Conserving and enhancing wildlife habitat.
- Conserving and recycling nutrients
- Providing healthy and humane care for livestock
- Producing foods that are not derived from genetically modified organisms (GMO's).
- Continually improving farming/ranching practices.

Food Alliance, *(Food Alliance, 2011)*

Unlike many other designations sustainability should not be about creating a strap line that provides a commercial advantage over the competition. Sustainable agriculture should address the core trinity of challenges that face agriculture:

- Global food security
- Limited natural resources
- Climate change adaption and mitigation

And, because we want a sustainable solution that sustains indefinitely, we need to make clear in any definition the infinite timescale. We have to assume that we intend for mankind to persist. This is critical because it highlights the unsustainable nature of any finite non-renewable resource used in production.

Many definitions focus heavily on balance, many try to skew that balance in favour of economic or social issues. My fear is they also divert attention from the critical challenges, both are manmade principles that can evolve, whilst the trinity is absolute.

My definition is therefore possibly simplistic but it goes like this.

'Sustainable agriculture is a form of farming that is able to persist independently of non-renewable inputs, to increase production through the advancement and wider adoption of knowledge and to adapt and reduce the impacts it will face as a result of climate change.'

I am fairly confident that my small contribution to the myriad of definitions already in existence will not trigger a revolution.

But I am equally convinced we need metrics to describe the sustainability of any farming system and that these need to be flexible enough to cope with an ever evolving understanding of sustainability. The ultimate goal has to be to demonstrate that farms are operating within the principle of 'one planet farming'; where the farm is operating within the constraints of the resources available on one planet. Such a system will never be perfect but as long as it provides consistency it can be used to monitor progress or benchmark one farm over another.

Many systems already exist to measure farm performance and many claim that they are measures of sustainability though they tend to be focused on very specific areas such as carbon footprints, financial performance or animal health. By bringing together as many sustainability indicators as possible we can begin to calculate a farm's sustainability and may even express it using the methods developed by the Global Footprint Network (*Global Footprint Network, 2010*) in terms of the farm's ecological overshoot.

There are a number of examples around the world of countries that have not just embraced sustainability but which have also started to measure it. Cuba is one such dramatic illustration. Almost overnight it was forced to shift to a more sustainable agricultural model.

After the collapse of the Soviet Union's communist regime in 1990 Cuba found itself literally marooned in the Caribbean. The country had depended on trade with the various socialist regimes of Europe and the Far East. In return for exports of sugar cane, citrus, coffee and tobacco the socialist states provided all the modern inputs associated with agriculture such as fertilisers, oil and pesticides. Without this Cuban agriculture virtually collapsed; millions of livestock died as feed and veterinary supplies dried up, tractors stood idle for lack of fuel, and staple food imports such as wheat flour and vegetable oil had to be rationed. The average daily calorie intake of a Cuban fell from 2,900 a day to 1,800 in 1995 (*Jason, 2007).* Fidel Castro euphemistically coined the phrase 'The special period' to describe the country's difficulties.

The crisis Cuba faced prophetically demonstrates how vulnerable modern agriculture can be. Before 1990 Cuba used over 1 million tonnes of fertiliser and 35,000 tonnes of pesticides per year, today the figures are 90,000 and 1,000 tonnes respectively. The country was forced to learn how to grow food on a large scale without reliance on petroleum based inputs. It effectively became organic, not through ideology but necessity. Though the country still imports 80% of its domestic food requirements (*Neill, 2008*) food availability has increased significantly because the country has got to grips with alternative production systems and with this has come an appreciation of the principles of sustainability; case study 2 shows how for a typical Cuban research project it is the measure of sustainability that is a key aspect of the performance of the system. Interestingly the range of indicators includes no reference to financial return; sustainability is largely defined by the output of food and environmental goods in relation to the amount of energy invested.

CASE STUDY 2: CUBA'S SUSTAINABILITY REVOLUTION

Today Cuba is a leading proponent of sustainable agricultural methods. The country's agricultural research sector has focused on diversified, integrated, self-sufficient systems. One such project was the development and evaluation of integrating crops, dairy cattle and tree farming. The project carried out by the Cuban Grass and Forage Research Institute (*Monzote, April 2002*) stands out for me not because of the subject matter but because of the way in which it assessed the sustainability success of the project.

The project measured sustainability indicators on 14 separate dairy units over 6 years as the farms moved from the typical specialised external input dependent dairy system to an integrated medium scale crop-livestock-tree system.

Indicator		Range
1	Milk production (t/ha)	1-3
2	Food production (t/ha)	1.9-6.1
3	Reforestation level (trees/ha)	53-277
4	Wildlife diversity (total species)	46-78
5	Food products (number of edible products)	11-20
6	Organic fertiliser production (t/ha)	1-2.8
7	Intensity of work (hours/day/ha)	0.8-4.5
8	Energy efficiency (calories produced/calories invested)	4.5-10.6

Figure 4: The average values for sustainability indicators across 14 Cuban farms

The results are shown as a web graph; so that as many axes can be added as there are sustainability indicators. The indicator absolute values are converted to a common scale making it reader friendly. The system forces management issues into the open and demonstrates progress or failure over time. It is especially powerful at presenting the relationships between indicators. They can help farmers and particularly researchers appreciate the holistic nature of farm operations.

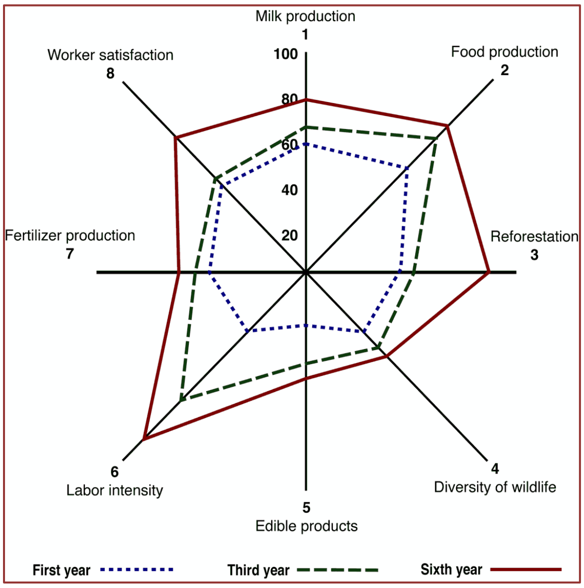

Figure 5: Web graph showing trends in sustainability indicators on a Cuban farm

3.4 THE CONSUMER & RETAILER

Consumers are increasingly becoming aware of the concept of sustainability even if in most cases they are not clear about what it actually is. Anything that interests consumers automatically appears on the radar of the retailers and in turn their suppliers. Marks & Spencer's were one of the first retailers out of the blocks to develop a sustainability strategy. The store launched its sustainability initiative in 2007 and called it 'Plan A' because, as they put it, there was no plan B. The plan was based on 5 main pillars;

- Climate change
- Sustainable raw materials
- Waste
- Fair partner
- Health

Amongst the 5 main pillars were 100 separate commitments to address over a 5 year period that have now been increased to 180 commitments to take the company through to 2015. They have, rather ambitiously, now set themselves the target of being the world's most sustainable major retailer.

The Marks and Spencer's philosophy recognises the difficulty in defining sustainability; which can include animal welfare, greenhouse gases, waste, ethics and more? Their approach has been to *almost* suggest to the customer that sustainability is such a complicated amalgam of strands, that as long as he buys products from the company he can be sure all that sustainability is being managed.

While the public may not understand all of the subtleties and interactions that determine the sustainability of every activity or product around them they know enough about the debate to understand when some things are obviously wrong. It is quite probable that this will lead to a social unacceptability of environmentally negative activities, just in the same way that attitudes have changed through history towards things like child cruelty, drink driving and more recently smoking in public. The large SUV in the drive or the diversion of grain to bio-fuels could all become widely accepted as just wrong.

The greening of the supply chain is inevitable and irreversible. But as yet not all retailers have woven it into their very fabric in the same way in which Marks & Spencer's have. In January 2008 the CEOs of the main food retailers were asked to rank the issues that concerned them the most and at the top came 'Corporate and social responsibility'. Eighteen months later, when the global downturn had hit, the same group of company CEOs ranked corporate and social responsibility only at fifth place *(Hughes, 2010*).

Despite this, many of the big retailers are rolling out sustainability initiatives even if, at this stage, they are projects rather than a set of core values. Mike Duke the CEO of Walmart in 2009 launched its 'sustainable product index' for 1,600 products. Its eventual aim is to roll out a customer facing sustainable product index for all of it products. At the launch Mike Duke said

'At the height of the recession we promised that we would broaden and accelerate our commitment to sustainability at Walmart…

…I appreciate that the world now has higher expectations of our company. So we must raise the bar. We must continue to meet the social expectations and obligations ahead. Walmart will never look back".

Tesco has also looked to colour themselves green. Terry Leahy once said

'Tesco's future is inextricably linked with taking a leading role in a more sustainable food system'

When retailers start to talk about sustainability then suppliers need to take note. Most retailers have little opportunity to deliver sustainability without the partnership of their suppliers. Besides operating a few shops the retailers have little direct contribution to the lifecycle of most products passing through their premises. Whilst they may be able to fiddle about buying green energy for their stores or improving the efficiency of their refrigeration, if they want to deliver significant sustainability promises to their customers they need the help of other contributors to the life cycle of their products.

One manufacturer that has been very proactive in this area is Unilever. Unilever is a global company with manufacturing operations in 100 countries and customers in 160. It claims that every day 2 billion people use its products every day. Sustainability has become embedded in the company's psyche over the last 15 years through the creation in 2010 of its 'Sustainable Living Plan'. The plan ambitiously sets out over the next decade the company's aims to double the size of the business while halving its environmental impact. By 2020 it has set out to help more than a billion people take action to improve their health and wellbeing, halve the environmental footprint of its products, source 100% of its agricultural raw materials sustainably, and link more than half a million smallholder farmers and small-scale distributors to its supply chain.

Unilever's plan has three distinctive features; covering social and economic, as well as environmental challenges. All of Unilever's products and brands are included. It also covers the company's entire value chain, from sourcing raw materials to consumer use of its products and their disposal. With such an expansive product range across so many different countries this represents a massive undertaking.

The company has also set itself some stretching targets. The billion people target is not just about reaching people with socially beneficial products such as soap, toothpaste and safe drinking water, but is also about helping people to change their behaviour so that habits such as brushing teeth twice a day become part of everyday living.

Lifebuoy soap, for example, which is sold in 55 developing and emerging countries, will be used to change the hygiene behaviour of 1 billion people by showing them the health benefits of hand washing with soap at key times of the day, such as before preparing food or after going to the toilet. This has the potential to cut diarrhoea causes by 25%, and reduce acute respiratory infections, two of the biggest killers of children under five, while increasing school attendance by up to 40%.

Halving the greenhouse gas (GHG) footprint of Unilever products across their life cycle by 2020 represents an equally big challenge. The company has led the way in developing lifecycle assessments for its range of products. The assessments reveal some interesting information. The Unilever Director of sustainability, Jan Kees, claims that for a typical Unilever product only 5% of the environmental impact of that product comes from manufacturing. By far the largest contribution comes from consumer use which accounts for 68% of the total, most of it caused by people showering, washing hair, doing laundry or cooking the product.

The other big contributor, at 26% - to environmental impact, is the primary production phase which includes agriculture.

Around half of Unilever's raw materials come from agriculture. As one of the biggest food companies, it is also one of the world's biggest buyers of agricultural products such as tea, tomatoes, and dried onion and garlic. So far, just 10% of its agricultural purchases come from sustainable sources. Among brands helping Unilever reach its 100% target are Ben & Jerry's who have committed to sourcing all ingredients that Fairtrade certification can be applied to from Fairtrade producers by 2013. Their decision to make all the tea in their Lipton Yellow Label and PG Tips teabags sustainable by 2015 has already resulted in more than 38,000 smallholder farmers gaining Rainforest Alliance certification, providing improved working conditions for 175,000 tea growers.

The implications for farmers are clear. Where retailers or processors make commitments to improve sustainability much of that responsibility will fall to the farmers and where sustainability was once a niche value that could often demand a premium, it will shortly be the norm for all premium products and in due course for any product that seeks listing.

The Carbon Trust intends to measure retailers' performance in reducing greenhouse gas emissions, the results of which will be published in the form of a league table. In such an incredibly competitive sector no supermarket is going to want to see its name at the bottom of that table and they will need to work closely with their suppliers to identify ways to improve sustainability. This has already been realized by many companies in the agricultural sector. Two examples are Oserian a cut flower producer in Kenya and Stonebuhr a specialist flour producer in Washington State, both of which are businesses with high degrees of sustainability that realise that the market may not recognise the green but will probably punish the 'un-green.'

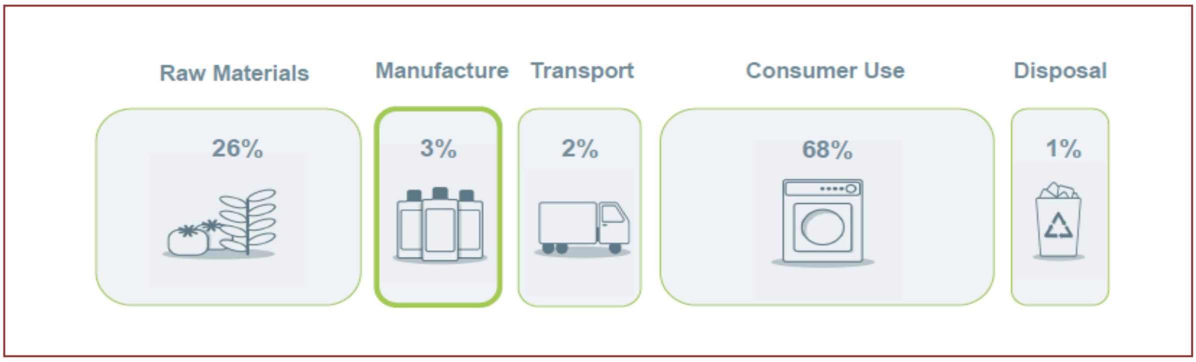

Figure 6: The environmental impact through the lifecycle of a typical Unilever product.

CASE STUDY 3: OSERIAN, RIFT VALLEY, KENYA

The Kenyan flower industry first emerged in the 1960s but it was not until the 1980s and 1990s, when significant investment flowed into the sector, that it become one of the most significant flower producers in the world. Today it is one of Kenya's fastest growing sectors at almost 20% growth in some years; it is also the country's second most important earner of foreign currency after tea, with annual sales worth $250 million a year. In a country in which half of its 37 million people live in poverty the industry not only employs 55,000 people directly, but indirectly supports over 2 million dependants. There are over 5,000 flower farms in Kenya but 75% of production comes from just 25 large companies. Of these Oserian, located on the shores of Lake Naivasha in the Rift Valley, is the largest single flower production site.

'Oserian' comes from a Maasai word meaning 'place of peace'. At one point the area was far from peaceful. The farm sits above a gash in the earth's crust, the valley is surrounded by extinct volcano craters and not far below the surface bubble geothermal springs. It was established originally as a 6 hectare vegetable production farm by a Dutch immigrant who fought as a marine in WWII before moving to Kenya. Today it is a 245 hectare production site which exports 400 million stems a year, mainly roses and carnations. The farm is a shining example of a business that has embraced the integrated nature of true sustainability rather than focussing on single issues such as its carbon footprint.

Social responsibility is a key element of that integration. The farm employs some 6,000 workers, 90% are on permanent contracts and around one third are female. The company provides either free housing or a housing allowance for its workers; in total it houses 10,000 people when dependants are included. The company provides healthcare facilities, primary schools, crèches, social clubs and sporting activities. The children of all workers are provided with schooling at both primary and secondary level. In addition, 10% of pupil numbers are made up of local children whose parents do not work on the farm. Bursaries are offered for college and university places, while for others a further education college operated by the company provides courses in vocational subjects such as knitting, tailoring, computing and business management.

Wages, frequently a cause of dispute in parts of the Kenyan flower industry, are by comparison generous at Oserian. The lowest wage on the farm is double that of the Kenyan minimum wage or the union's minimum wage. For new mothers the company provides 3 months' maternity pay.

The second key strand of the company's sustainability is its environmental practices. The farm is using geothermal energy; wells drilled into the geothermal tectonic plate produce both steam and carbon dioxide. The steam is used to heat the greenhouse, drive a 2 MW power plant and as a sterilant instead of chemicals. The CO2 is piped to the greenhouses as a fertiliser to increase production.

Figure 7: Part of the Oserian 450ha complex of flower production greenhouses on the shores of Lake Naivasha.

CASE STUDY 3: OSERIAN, RIFT VALLEY, KENYA continued

Additionally, over 80 percent of Oserian's crops are grown using hydroponics with a medium manufactured on site using ground volcanic pumice. Nutrient provision can be determined accurately to enable optimum use of nutrients whilst efficiency is further improved by the return of excess hydroponic water from one flower species to another thereby also reducing disease transmission. As a final measure a constructed wetland has been created through which run off from the greenhouses and ancillary buildings is directed. The 4 stage process is designed to remove, through biological means, any excess nutrients and pesticides that would otherwise have polluted Lake Naivasha.

Oserian has embraced the principle of integrated pest management (IPM). This makes use of a combination of plant nutrition and bio-control agents. Biological substances manufactured by 'Realm IPM' (see case study 16) are designed to prevent and combat a range of diseases that affect flowers without the use of chemical pesticides.

Figure 8: Warthog passing by at Oserian. Wildlife and flower production thrive together

Conservation is a key feature at Oserian. An 18,000 acre wildlife park has been created around the farm, often by reinstating forestry on previously wheat growing areas, and to help this they have established their own tree nursery which generates over 50,000 seedlings per year. The park provides a key wildlife corridor for animals from the nearby Hells Gate National Park to reach the shores of Lake Naivasha. So successful has the initiative been that it is now home to 14 breeding White Rhinoceros.

The company claims that independent assessors from Bristol University have calculated that the carbon footprint of each Oserian rose including air freight is one tenth that of a rose grown in Holland where greenhouses are artificially illuminated and heated 24 hours a day, generally using non-renewable energy sources. Many growers are acutely aware of the criticisms heaped upon them relating to food miles and the growing of flowers in a country which is short of food, but point out frequently that in terms of sustainability they have systems that are able to take advantage of the significant natural suitability of the region to grow flowers. They add that self sufficiency is not the only solution to eradicate food poverty, and that economic development can be even more powerful.

CASE STUDY 4: STONEBUHR FLOUR, WASHINGTON STATE, US

Figure 9: On the left side is a field that was conventionally cultivated whilst to the right is an area that has remained in natural vegetation, the soil erosion equates to over 1 foot

Stonebuhr flour is a story about a group of wheat farmers in the Pacific North West states of Oregon and Washington who saw their soils disappearing. They also felt that they had lost touch with the people who eventually ate their food and wanted to do something about it. Those farmers, led by Fred Fleming and Carl Cooper, set up Shepherds Grain a buying group essentially aiming to provide family scale farms with a sustainable future in the industry.

The group set about making itself unique in the supply chain by signing up to production standards set down by the 'Food Alliance'. This is a third party certification and inspection scheme for the production, distribution and processing of 'sustainable' food. Across the US the organisation covers over 6 million acres of production. The main strand of Shepherds Grain's interpretation of sustainability is soil protection. Based in a region of rolling hills where past cultivation has resulted in high levels of soil erosion, the growers in the group have embraced zero tillage practices. The second strand of social responsibility focuses on closing the gap between the customer and producer; they describe it as 'naked' marketing providing full transparency for the customer of what they do throughout the production cycle. Fred Fleming puts it like this: "We want to bring the customer back to the farmer and the land". The third main strand is about keeping the 33 medium sized family farms covering 65,000 acres that make up the group viable. This is done through full transparency of cost of production, backed by data processed by a local university.

The significant breakthrough came in 2002 when Josh Dorf purchased the 100 year old Stonebuhr Flour and set about returning to business basics. To him this meant building on the brand's solid reputation as a high quality artisan product. By forging a strategic link with Shepherds Grain he was able to source a high quality product with a credible record of sustainability. Stonebuhr became a significant outlet for Shepherd's Grain which now sees its product on all the major retailer shelves.

Stonebuhr has adopted some unique marketing tools to support its message of sustainable sourcing. On every bag of flour they sell is a best before date, or 'Julian day' as it is referred to in the USA. By entering this date into a page on the company's website the customer is taken to a page about the farm on which the flour is produced where they can also see a full biography of the family who run the farm.

4.0 THE ISSUES

Summary

In the next 20 years agriculture will experience an unprecedented confluence of pressures. Population is increasing at more than 2 people per second, or 200,000 per day, and is set to rise to 9 billion by 2050. Thereafter growth will slow considerably stabilising at between 9 and 10 billion people. To date the population time bomb has been defused largely by economic development. What is needed is a final push to create the resources to cope with the 2050 population blip. Population growth has many paradoxes, not least that to reduce growth through lower birth-rates countries need to be lifted out of poverty. The debate often centres around birth control but much of the population growth will be the result of an ageing population

4.1 A CROWDED PLANET

The population challenge comes from two separate angles. Firstly, there is the sheer number of people on the planet whilst secondly a growing proportion of that number is being lifted out of poverty and as a result becoming significant consumers of the world's resources.

The growth in world population only began in the early 1800s when the world's population stood at a modest 1 billion. Growth was relatively modest for the next 150 years reaching 2.5 billion in the post war period. It was after 1950 that growth really accelerated until in October 1999, just two months before the dawn of the millennium, the world's population had reached 6 billion (United Nations Population Division, 1999). The best estimate of the population today (July 2011) is 6.96 billion (*US Census Bureau, 2011*). It is important that we appreciate that despite this headline there should be no suggestion of runaway population growth. Incremental population growth has already peaked. Figure 10 shows how over the last few decades the annual incremental increase in population peaked in the late 1980s at 86 million per year.

Population growth was at its fastest in 1963 at 2.19% a year, whilst today that rate has almost halved to 1.15% and is continuing to decline. The decline will reduce growth to a projected 1.00% by 2020 and 0.5% by 2050. The United Nations Department of Economic and Social Affairs predicts that at current trends the world population will stabilise at 10

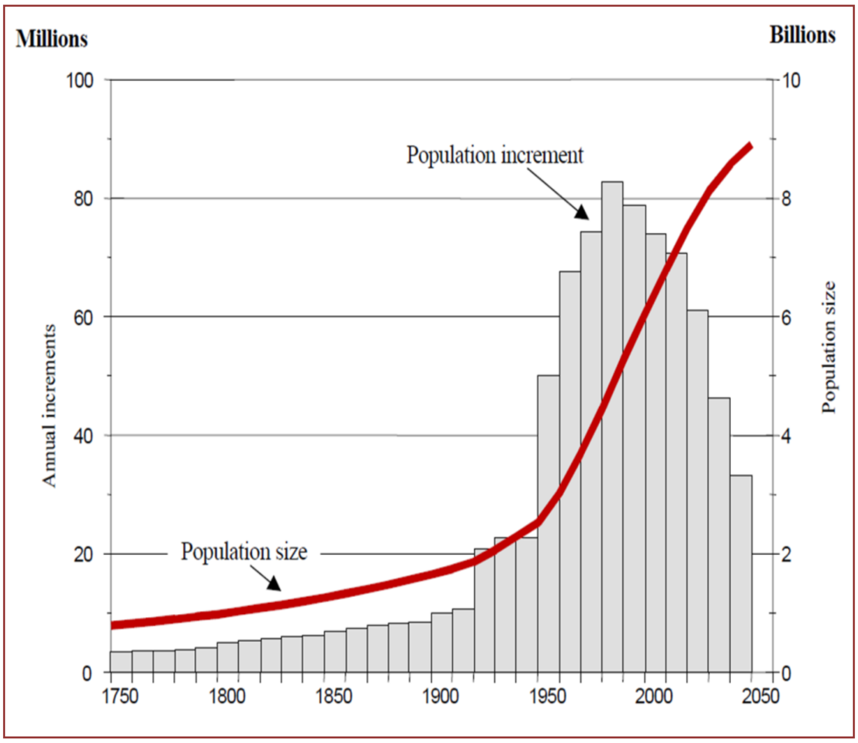

Figure 10: Long-term world population growth, 1750 to 2050 (United Nations Population Division, 1999)

billion in the year 2200 (*Evans, 2009).*

The changing dynamics of population growth are curious. What we have effectively seen until recently is a period of slow population growth. Up until 1927 it took 123 years to add 1 billion people to the world yet by 1999 it took just 12 years. This period of frenzied growth is coming to an end after only 100 years. Once we reach 9 billion people, the next step to 10 billion will fall back to 129 years (figure 11).

World Population reached		
1 billion in	1804	
2 billion in	1927	(123 years later)
3 billion in	1960	(33 years later)
4 billion in	1974	(14 years later)
5 billion in	1987	(13 years later)
6 billion in	1999	(12 years later)
7 billion in	2013	(14 years later)
8 billion in	2028	(15 years later)
9 billion in	2054	(26 years later)
10 billion in	2183	(129 years later)

Figure 11: World Population Milestones (United Nations Population Division, 1999)

In 1798 the economist Thomas Malthus published his famous theory on population growth and agricultural production (*Malthus, 1798*). Malthus took the US as a model of population growth because the country was barely 25 years old at the time. He predicted that population would grow exponentially (1,2,4,8,16,32,64,128,etc) but suggested that agricultural production could only grow arithmetically (1,2,3,4,5,6,etc). Malthus believed that land available for agriculture would be the limiting factor and that eventually the nightmare of starvation would take over.

Malthus's nightmare of continued exponential growth was not correct. What we are now faced with is not 'a race to maintain the status quo' but rather a 'last final effort' to cope with the 2050 population blip.

4.1.1 THE DEMOGRAPHIC DETAIL

There are few conferences today that you can attend without hearing mention of 9 billion people by 2050. It is has become a cliché occasionally supported by a growth curve and invariably used as a way to justify and promote vested interests. Population growth is, however, much more complicated. Different parts of the world are at very different stages on the population curve. This is often referred to as the demographic transition. The developed industrialised countries are principally Europe, North America, Australia/New Zealand and Japan. As a group these countries are forecast to stabilise as their transition is largely complete, in line with their relative economic maturity. Within this group there are also different dynamics at play. Figure 12 shows how the trend lines of both North America and Europe are set to diverge as North America's population increases by 37% to 2050 (from 350 million to 470 million) while Europe declines 20% from 730 million to 590 million. North America's continued growth is attributed to high levels of immigration and continued high birthrates. In Europe immigration levels do not offset low birth rates and in some of the Eastern European states the population is already declining. In the UK we will see a trend similar to the US; numbers are set to increase by 14% by 2100 taking the population to 70 million.

It is in the developing countries of Africa, Asia and Latin America that most of the world's population growth will take place. Here the demographic transitions started later and in some regions have barely begun. Among these regions Asia alone, at 4.2 billion people, represents more than half of the world's population. The two largest countries in this area are China with 1.35 billion followed by India with 1.21 billion. Current forecasts *(United Nations Department of Economic and Social Affairs, 2006*) suggests that at current rates India will overtake China by 2050 as the world's most populated country.

Africa currently has a population of 1 billion, and is subject to the highest growth rate of any region. Its projected growth rate will take it beyond 2.5 billion by the end of the century.

In Kenya and Uganda population growth rates have been almost 4% per year, and at this rate the population doubles every 20 years. Such growth rates are unparalleled. Two principal factors explain such high growth rates;

- Access to the medical technology which proliferated after World War II in other parts of the world, and significantly reduced death rates.

- A considerable lag in the reduction of birth rates, partly explained by the very traditional nature of some societies.

It is clear then that the areas of real risk are those least developed countries where population growth does not show the same signs of slowing or even falling as in those regions where development has taken them further down the road of demographic transition. It is those regions with continued high rates of growth that will suffer the greatest pressure on their natural resources, risking growth beyond the sustainable carrying capacity of their land and associated resources.

For many of the African countries problems are being compounded by the continuous sub-division of farms to accommodate the growing population, and tension over land rights and political inability to adequately create a stable environment of stability for growth. In 2008 in Kenya following an election in which land policy played a central theme, these tensions spilled over into street riots and violence.

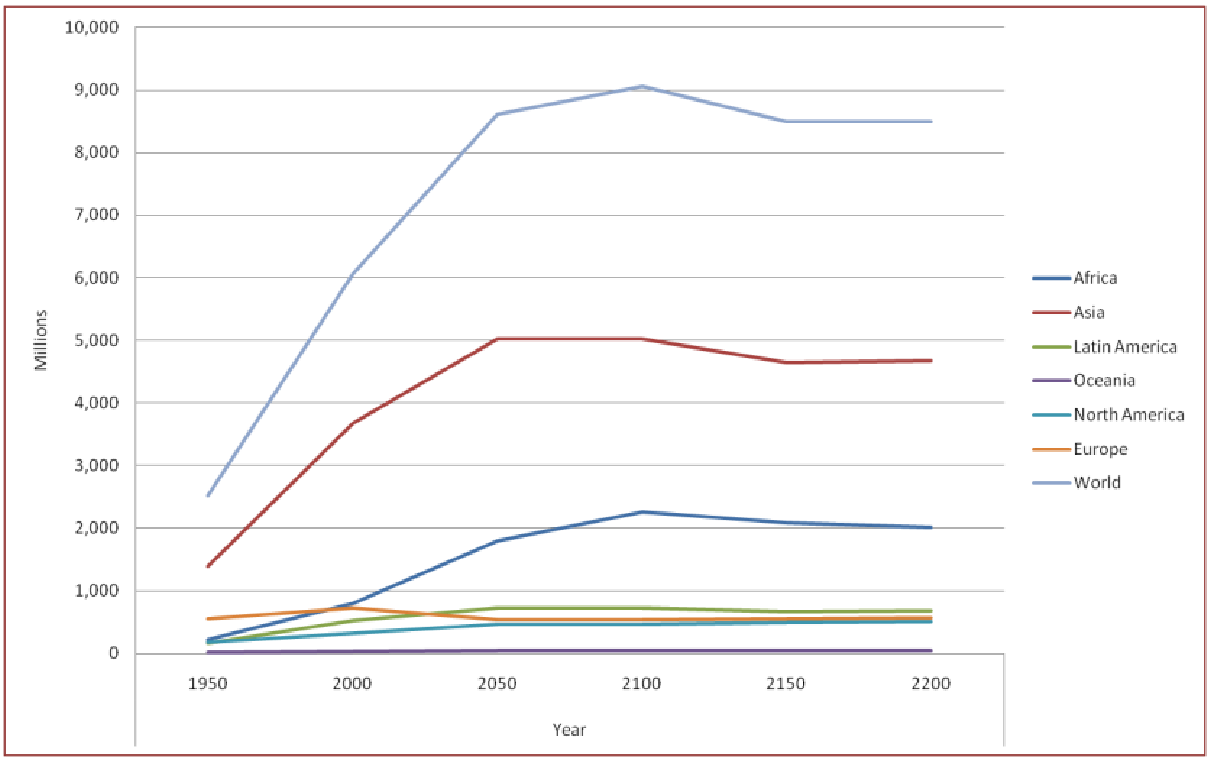

Figure 12: Population projections by region generated from United Nations data (United Nations, 2004)

CASE STUDY 5: CHINA'S UPHEAVAL

China represents a classic example of a rapidly developing country. During the last 30 years the country embraced many of the principles of capitalism. The shift from its communist roots has been dramatic, and from the humblest peasant to the most sophisticated captain of industry the focus has unashamedly been the pursuit of wealth. The result has been runaway growth; the economy has recorded consistent double digit growth which has had major environmental, economic and social effects. One of the most striking effects is the shift from a rurally based economy to an urban focused nation. Huge numbers have drifted from the land to the cities and it is striking to see many rural villages populated largely by children and the old as the working population leave their children in the care of the older generation and head to the growing urban centres in search of lucrative work in the booming construction and service sectors. In the 30 years to 2009 the proportion of the population living in rural areas has fallen from 81% to 53%. By the end of the decade China's population will be predominantly urban. The shift from an agrarian based economy is reflected in the proportion of the nation's GDP derived from agriculture, which has fallen from 30% to 11% and is still reducing. One of the effects of the rapid economic boom is rapidly increasing wages which in some sectors have almost doubled in the last 12 months. One University professor in Beijing told me how rural migrants recruited to work in the campus could simply not be relied on to return the following semester because they continually move to higher paying jobs.

As economic development has escalated China has become increasingly reliant on the rest of the world for its food supplies. Agriculture is no longer a source of foreign currency because the country has moved into a food trade deficit. The main imports are vegetable oils, meat and soybeans. Globally the world trade in soya is $35 billion of which China alone accounts for $23 billion (Lam, 2011).

	1980	2009
Gross Domestic Product % from agriculture	30	11
Population % in rural areas	81	53
Population % employed in agriculture	69	39
% of agricultural production exported	20	3
% of food derived from imports	15	4
% of expenditure on food in urban areas	57	37
% of expenditure on food in rural areas	62	41

Figure 13: The changing economic influence of agriculture in China (Bingsheng, 2011)

China is a huge country with incredible variations in climate, soils and topography. Much of the country presents huge limitations in its suitability to support agriculture and particularly crop production. China has access to 7% of the world's arable land and 5% of the world's fresh water and yet it has to support 19% of the world population. In the last 60 years the amount of arable land has halved as a result of desertification, urbanisation and salinisation. Despite this, overall production has increased, but China has a huge challenge; the current population is 1.34 billion and notwithstanding the draconian birth control policy is still set to peak at 1.5 billion. To meet this challenge China is investing heavily in agricultural research – with an increase from RMB 400 million to RMB 1.2 billion in just 3 years. The country is also searching the world for opportunities to secure additional land resources. The result has included the purchase of farms throughout Africa, Australia and the United States.

4.1.2 AN AGEING POPULATION

As birth rates fall and life expectancy increases the natural result is that in many countries the population ages rapidly. From today through to 2050 half of the increase in the world population will be accounted for simply by an increase in the number of people over 60. This process is expected to continue indefinitely.

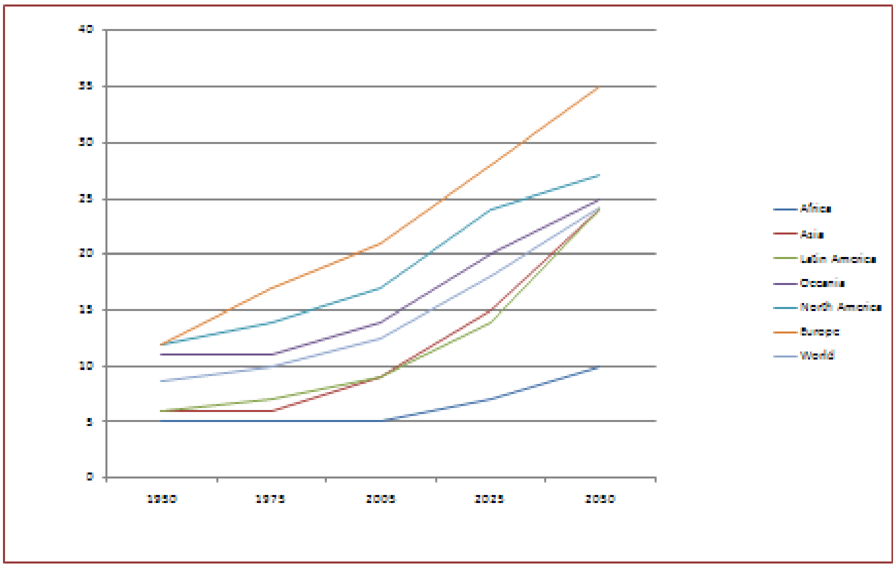

Figure 14: The percentage of the population aged over 60 (Population Division Department of Economics and Social Affairs, 2005)

The developed countries have already aged substantially in the run up to 2011 (figure 14). This trend will be for continued growth at about 2% a year. Europe's elderly population will account for 35% of its total population by 2050. Relatively little ageing has occurred in Asia or Latin America until now, though that trend is set to change and increase over the next few decades. The exception is Africa which is at such an early stage of transition that it will require many decades before an effect is seen.

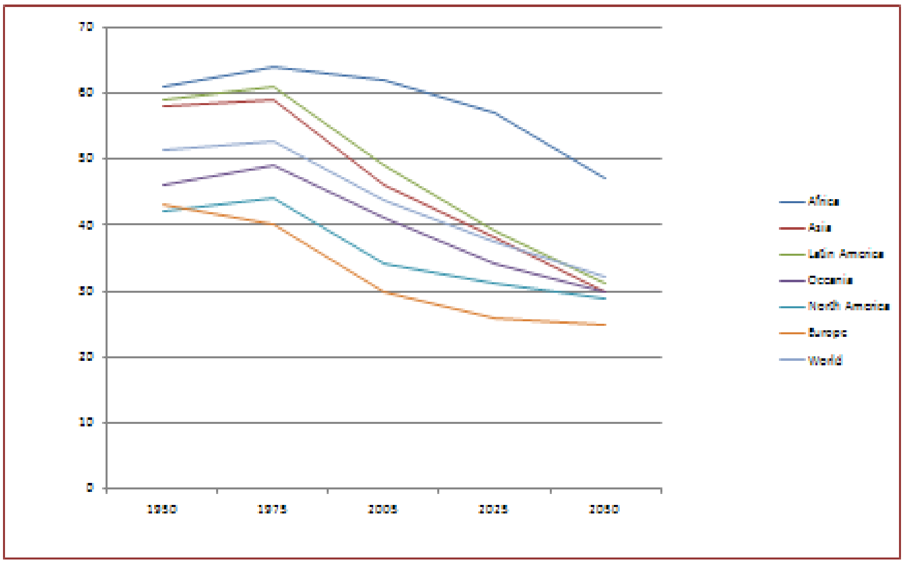

Figure 15: The percentage of the population aged 24 or less (Population Division Department of Economics and Social Affairs, 2005)

The opposite trend applies to the number of people below the age of 24, as shown in figure 15. In less developed countries the population is still relatively young. Typically children under 15 account for 30% and young people (15-24 years) for a further 19% of the population in the lesser developed regions whilst in Africa children account for 40% and young people 20%. In the developed nations this is more typically 17% and 13% respectively.

The implications are clear in that each region will see unique patterns of demand and consumption for everything from education to the consumption patterns of food, water and energy. In Kenya in particular this demographic skew is resulting in the ever decreasing size of farms as they continue to be subdivided in a desperate bid to provide the next generation with a land holding.

4.1.3 THE DRIFT FROM THE COUNTRYSIDE

Urbanisation is the product of industrialisation and wealth creation. It began in the northern hemisphere in the 19th century - and continued throughout the 20th century - with the start of the industrial revolution which brought employment opportunities to urban centres via work in the manufacturing and service sectors. The draw was not just for surplus labour from the countryside but also those attracted by higher incomes and improved standards of living.

Urbanisation was not a feature of the southern hemisphere until the latter half of the 20th century.

In 1950 the percentage of the world's population living in urban areas was 29% with a range from over 51% in Europe to just over 15% in Asia and Africa. Today the world's population living in urban areas has crossed the 50% mark. Nevertheless many parts of the world remain predominantly rural in nature. In Africa and Asia 3 in every 5 people still live in the countryside. Despite this the historic and predicted trends in urbanisation, shown in figure 16, are clear.

The population division at the United Nations Department of Economic and Social Affairs Department closely monitors population trends and every two years it revises its predictions on the effects of these trends on urbanisation. The last revision, in 2009, suggested that an additional 2.9 billion people will move to urban areas between 2009 and 2050. The anticipated world population growth in this period is only expected to be 2.3 billion meaning that all of the future growth in the world's population is going to be absorbed by towns and cities. The results for worldwide agriculture are clear; fewer people in the countryside will have the job of feeding greater numbers of people in the urban areas.

This will require continued improvements in output per capita of farmer. One of the other effects of urbanisation is the loss of agricultural land. Most large urban areas are located on high quality farmland making the loss of that land especially problematic.

The effect of these factors can be seen clearly in the rapidly expanding Chinese capital city, Beijing (see case study 6). The loss of high quality deep alluvial soils which form the basis

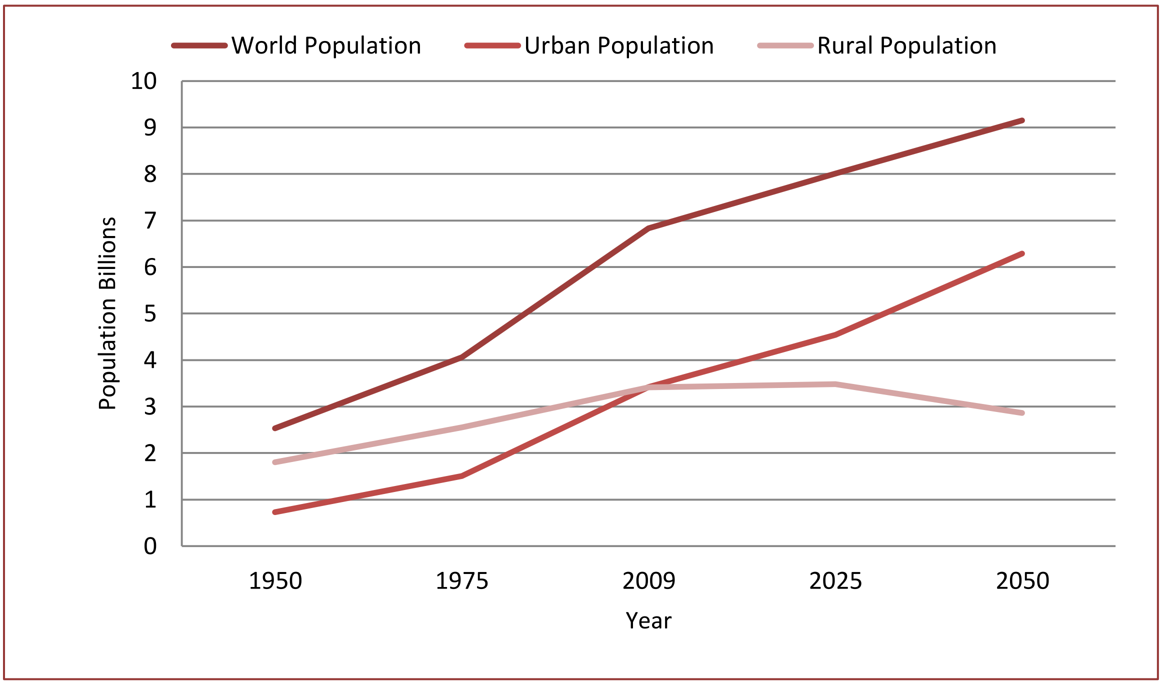

Figure 16: The trend in the numbers of people living in urban and rural areas (Division, 2009)

of the agricultural land surrounding Beijing has to be a concern in a country that has 22% of the world's population but only 7% of the world's land suitable for crop production.

The shift from the rural regions to urban centres will not be equal around the world as figure 18 demonstrates; its impact is greatest in the developing regions of Asia and Africa. Asia in particular will see urban populations increase by 1.7 billion and in Africa the increase will be 0.8 billion. The net result is that by 2050 the urban population of developing regions will account for 66% of the population. This is less than the 86% of the population in developed countries which will live in urban areas and still below the world average of 69% forecast for 2050.

Today 3.4 billion urban residents are distributed among urban settlements of many different sizes and we often hear about the growth of megacities in many parts of the world. These massive concentrations of humanity contain over 10 million people, more people in a concentrated area than populate many entire countries of the world. While these are becoming a growing feature of urbanisation they currently only account for 10% of the urban population, and though they are expected to increase significantly (figure 19), the majority will reside in smaller urban conurbations of less than half a million people.

Figure 17: Abandoned farmhouse in Saskatchewan

The combination of rapid population growth and urbanisation produce rapid growth in towns and cities in the developing countries. The result all too often is an infrastructure that is unable to cope with the rapid growth. In many of the newest conurbations problems such as overcrowded schools, traffic congestion, air pollution and water shortages and pollution can develop. Some of these negative outcomes can also apply to developed regions as in the case of Los Angeles's famous pollution problems (figure 20).

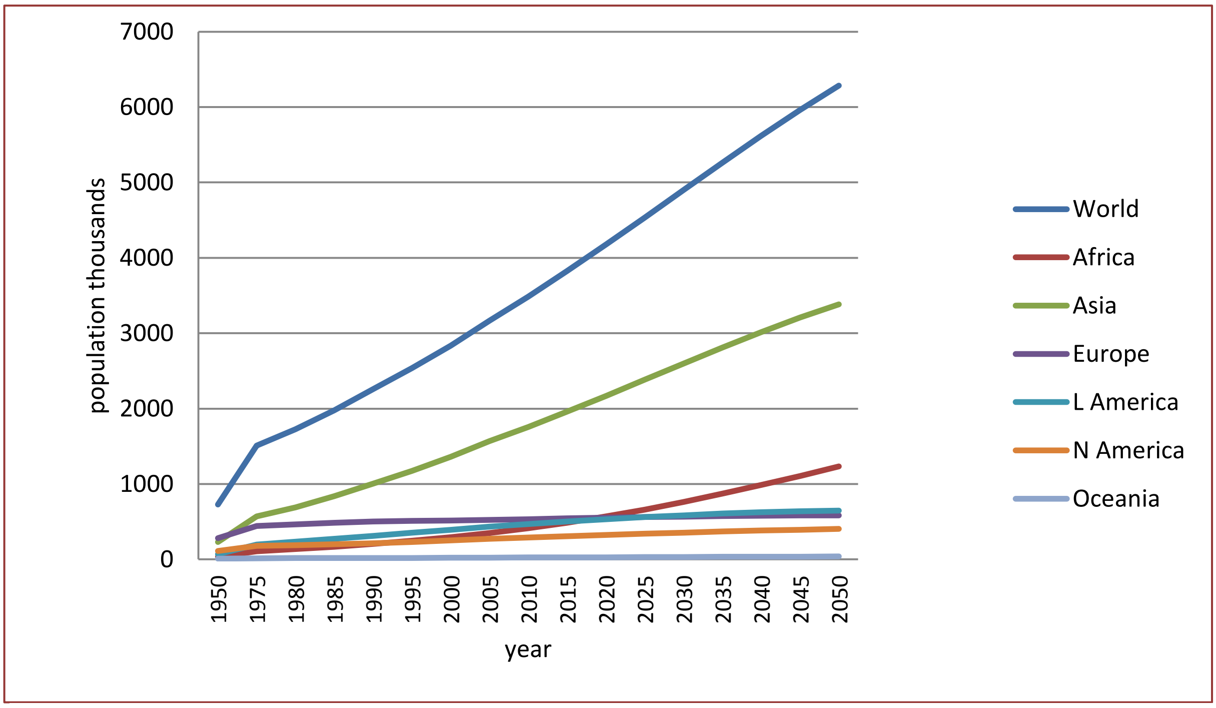

Figure 18: Urban, rural and total populations of the world and regions 1950-2050 (Division, 2009)

Rank	Country	City	Population
1	Japan	Tokyo	37,088
2	India	Delhi	28,568
3	India	Mumbai	25,810
4	Brazil	Sau Paulo	21,651
5	Bangladesh	Dhaka	20,936
6	Mexico	Mexico City	20,713
7	USA	New York	20,636
8	India	Kolkata	18,725
9	China	Shanghai	20,017
10	Pakistan	Karachi	18,725
11	Nigeria	Lagos	15,810
12	DRC	Kinshasa	15,041
13	China	Beijing	15,018
14	Philippines	Manila	14,916
15	Argentina	Buenos Aires	13,708

Figure 19: The predicted largest 15 megacities of the world by 2025 (Division, 2009)

Figure 20: The future megacity of Los Angeles is home to 4 million people and sits in the Los Angeles basin, for much of the year is bathed in air pollution (Photograph by David Iliff)

CASE STUDY 6: BEIJING'S RUNAWAY URBANISATION

Figure 21: Rapid expansion and construction in Beijing will take the city's population to over 15 million by 2025 (Division, 2009)

Beijing is located on the Northern China Plain. it is a municipality controlled by the central national government based in the city. To the northern, western and southern boundaries it is surrounded by Heibei province and by Tianjin province on the eastern side. The city is one of the world's oldest capital cities and was historically known as Peking. Up until 1978 its growth was modest; but the introduction in 1979 of economic and social reforms following the death of Chairman Mao Tse Tung unleashed massive investment and growth in both infrastructure and population for the city.

The city has developed radially from the oldest original part of Beijing which consists of Tiananmen Square and the Forbidden City of the Emperors who originally ruled the country.

Beijing traditionally consisted of the square, walled Inner City and the rectangular, walled Outer City to its south. The walls no longer stand, but in their place the Second Ring Road now outlines the Inner City, and canals outline the Outer City. As the City has grown, additional ring roads have been built and the total now stands at nine ring roads with a further two already proposed.

In the 1980s many industrial plants were moved from the central city to outlying areas. Much of the new housing was also outside the Third Ring Road, in medium- and high-rise buildings often built on former agricultural land. In the central city, office districts and shopping districts have been built or expanded. Many new buildings serve the increasing number of foreigners doing business in Beijing.

Partly because people's daily activities now take place in several parts of the city, traffic has increased greatly, and congestion is a major problem. A subway line now traces the former Inner City wall, and more lines are coming. Bicycles have doubled since 1979, adding to the congestion. Despite having largely a clean slate with which to start city planners are largely planning around the automobile and building roads. The number of cars in the city is growing faster than roads can be constructed creating major congestion; and in a bid to reduce traffic the government has imposed a car lottery. Car owners are prevented from using their cars one day a week, and the allotted day being based on the number shown on the car's registration plate.

The satellite images in figure 22 are provided by the US Geological Survey and clearly show the growth of Beijing from 1976 to 1991. The blue tones on the images represent buildings and pavement spreading outward from the centre of the city and replacing the red tones of natural and agricultural vegetation. The city has now grown far beyond its traditional core around the Inner City (which is visible as a bright rectangle).

CASE STUDY 6: BEIJING'S RUNAWAY URBANISATION

The satellite images were presented to the Chinese government by US researchers; the images showed that China is losing arable land to development at a rate two and a half times faster than was previously assumed. The government was moved to order tough new measures; new legislation passed by the National People's Congress in March 1997 made unauthorized land transfers punishable by up to five years in prison. In 1997 the State Council froze for one year all land transfers not specifically and directly authorized by the Council.

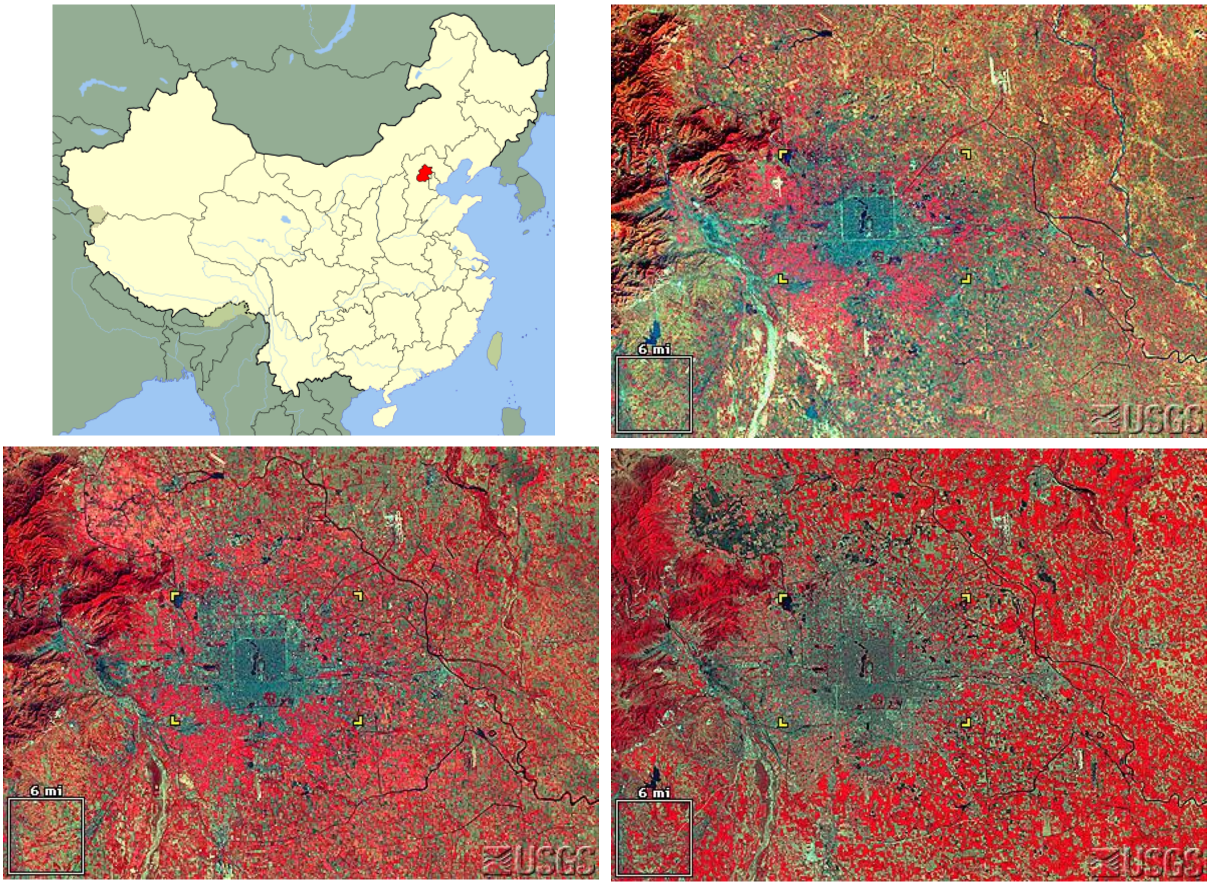

Figure 22: Top left: the location of Beijing in China, top right and bottom: Satellite photographs by the US Geological Service demonstrate the progressive urbanisation of Beijing (Campbell, 1997)

I found that all too often rural officials have little understanding of having regulations limiting the conversion of cultivated land. Local governments see the construction of housing or industry as a big money-maker; particularly in the case of industrial development where the local government is able to levy local taxes.

In a meeting with local officials, I was invited to examine a range of potential development sites for use by UK companies looking to locate to China. In every case the site was on high quality arable land used by local farmers for vegetable production. In one case the proposed site included a small village which the local government officials suggested could be easily relocated.

5.0 FOOD SUPPLY AND SECURITY

Summary

Feeding the world is not just about increasing production. There is enough food already out there but equitable access to food is complicated by economic, social and physical issues. The recent increases in food prices have had a devastating effect on some elements of the population for whom a safety net will be required, but it has also resulted in levels of investment currently flowing into agriculture that have not been seen in many years and which will result in increased production. It is notable that most of the increase in future output is going to come from the developing regions of Asia and Africa, because much of the developed world has reached a plateau in terms of production and indeed Europe is reducing output.

5.1 FOOD PRODUCTION

Agriculture began 10,000 years ago when the world's population was just 10 million, less than the current population of Beijing. Farming probably began with little less than a digging stick and a handful of wild seeds but that was the first stage of what was to become a technological journey through the millennia punctuated periodically by enormous leaps that improved the capability of the industry to return ever greater amounts of food from the efforts of each farmer.

Technological innovation was accompanied in equal measure by social changes. It was rarely enough to simply develop a new technology that allowed two grains to grow where previously only one had done so and often this could only be achieved where social progress was able to take place alongside. One of the most notable examples was the enclosure of common land in England through the 16th century until the 18th century, which allowed the application of techniques and, critically, the long term investment in land and agriculture that the open field strips that previously existed did not.

> *"Technologies are by themselves not enough… Too often the new technologies have been injected into communities with rapidly growing populations already dominated by excessive inequalities where, in the absence of countervailing policies, the powerful and better-off have acquired the major share of the benefits "*
>
> Gordon Conway, Chief Scientific Officer, Department for International Development (DFID).

In many parts of the world farmers are on a transition that progresses through a series of agricultural innovations. In different regions the progress along that technological journey varies, though, for all the destination is the same. So while England had its land reform revolution with the advent of the enclosure act, other regions have yet to reach that point on the journey. Professor Imasiku Nyambe from the University of Zambia described to me how land tenure in Zambia operates. No land is owned by individual farmers; instead it is held in two ways. A community leader such as a village chief distributes land to villages according to his preference, and all other land is government owned and is offered to farmers according to the preferences of government officials. The risk of abuse is obvious and yet arrangements of this type are common in many developing countries where they frequently limit the deployment of innovation and technology that requires the certainty of land tenure.

Few innovations have the power singularly to make dramatic changes in production; progress is generally the result of the compounding of several innovations. The enclosure act was an example of this; on its own the effect was minimal but when combined with innovations such as the introduction of the four course rotation and the adoption of new crops such as turnips and clover the result was tremendous. In the classic four course rotation (clover-wheat-turnips-barley) the rotation integrated livestock with crop production to re-cycle nutrients and take advantage of clover's nitrogen fixing feature. The result was a 50% increase in cereal yields by the end of the 18th century.

It was the 'Green Revolution' in the 1960s that next picked up the baton to ncrease production. Rather than do this by putting more land into cultivation technology now led the charge to produce more from existing resources. The green revolution focussed on a number of plant breeding and input developments. Among the innovations in plant breeding was day length sensitivity manipulation, straw shortening, disease resistance, and developments in the use of pesticides, fertiliser and water management.

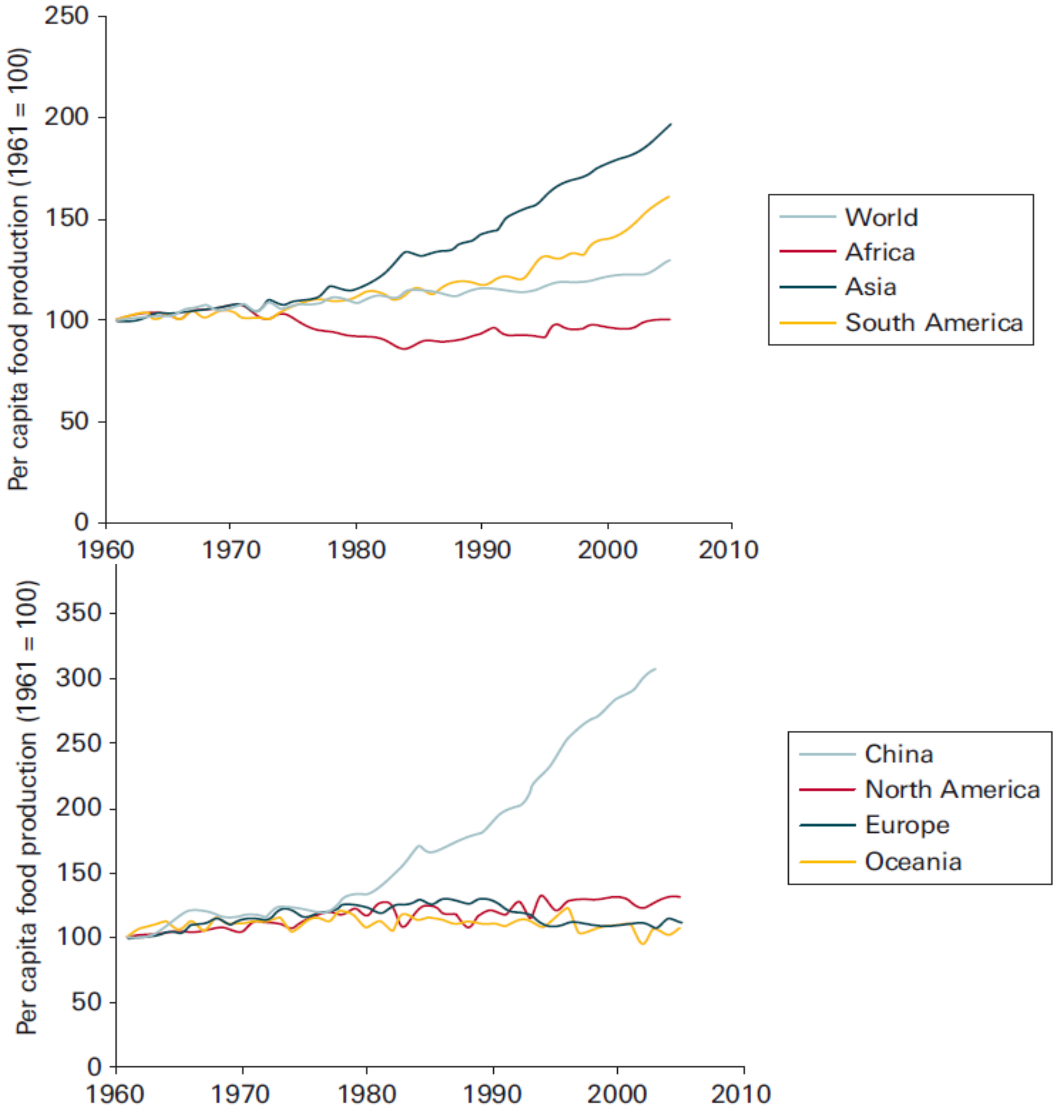

Figure 23: Changes in per capita agricultural production (1961-2005) (The Royal Society, 2009)

CASE STUDY 7: THE TIGER THAT LIKES MILK, THE UNINTENDED CONSEQUENCE OF DEVELOPMENT

In 1949, China under the leadership of Chairman Mao Tse Tung, embraced communism. It became an insular country with little influence on the world's economy or interaction beyond its boundaries. After his death in 1978 the country embarked on a series of economic and political reforms

As wealth increased food consumption evolved. In 1996 annual dairy product consumption in China was 8kg per person and by 2006 it had risen to 25kg. In 30 years production has increased 35 fold (see figure 1), making China now the world's third largest milk producer and yet consumption is still well below the world average of 80kg suggesting that the trend still has some way to go. The president of Fonterra recently suggested demand would further triple in the next 10 years.

Historically milk consumption in China has been low. Chinese people have a much higher incidence of lactose intolerance than in the West which, combined with a lack of refrigerators in homes and periods of food shortages, resulted in policies that discouraged animal production.

As reforms took hold a number of large milk processors, some of which were originally government owned, have been able to establish and grow rapidly. The two largest, Mengnui and Yili, both originated in the heart of the Northwest grasslands of Inner Mongolia where most milk production had taken place albeit carried out by the subsistence farmers of the grasslands. Elsewhere most cattle were mainly used as draft animals. Today, each of these dairies has a 16% share of the market and processing sites throughout the country. In 2007 these two massive companies had a combined sales revenue of $5 billion.

Many current dairy farmers grew up as crop farmers, and they purchased cows only recently as a result of initiatives by the milk processors or government. Finance was often provided by the processors and the loan repaid in milk supplies. Few farmers though have more than a handful of cows because the cost of a cow can equate to 2-3 years' net income for a farmer. Cows are kept in yards and twice daily walked to village milking stations where the milk is combined. A lack of experience of milk production means technical knowledge is very limited particularly the understanding of nutrition, so feed is usually based on by-products (see figure 24).

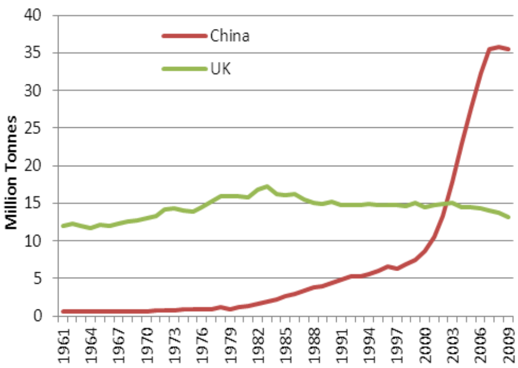

Figure 24: Right: Comparison of UK and Chinese milk production, million tonnes per year (source FAO) Left: With a limited cultivation of forage production most animal feed is based on by-products such as these maize plants which were being ensiled for a 3,000 head beef unit after the cobs had been removed for human consumption

CASE STUDY 7: THE TIGER THAT LIKES MILK, THE UNINTENDED CONSEQUENCE OF DEVELOPMENT : continued

The small scale model of production is proving unsuitable to supply a rapidly growing demand; it is inefficient and has become associated with contamination and poor quality milk. Demand growth is largely being satisfied by investment from the milk processors and foreign investors in mega dairies of up to 30,000 cows. It is estimated that there are now more than 200 dairies with over 500 cows in China with a significant number more on the drawing board.

The country is challenging for any large scale dairy operation. Land is in short supply and forage provision is difficult in a country with no culture of producing high quality feeds dedicated to animal production. Combine this with a land tenure system made up of millions of farmers each leasing only about 15mu (2.5 acres) from the government and the logistical problems become clear.

To deal with this many large units rely on imported high quality forages, principally alfalfa from the USA. The imbalance in trade between China and the USA means that shipping containers carrying consumer goods to the markets of North America often have to return empty to China. One recent report suggested that it was cheaper for growers in the Los Angeles area to send hay to Asia than to the north of California.

In a market where demand is constantly outstripping supply the unscrupulous look for ways to take advantage. The Chinese dairy industry was rocked in 2008 when the government announced a recall of melamine contaminated infant milk powder produced by the Sanlu dairy. Further investigation revealed that almost all Chinese dairy products were contaminated. Mengnui and Yili lost 80% of their sales in 10 days.

Melamine is a high nitrogen chemical used in the manufacture of plastics. It was being sold widely and openly in bottles with printed instructions on how to add it to simulate protein in milk that had been diluted with water. The consequences were serious; six babies died and more than 290,000 people suffered from poisoning. The Government reacted robustly and two people were convicted of mixing the chemical with milk and were shot, whilst a third received a suspended death sentence and a number including the Chairwoman of Sanlu were given life sentences. Sanlu was bankrupted and Fonterra, which had invested $153 million in 2005 to acquire 43% of the company and make their first steps into China, came away with nothing.

Public confidence in Chinese dairy products was destroyed; the standing joke was that you should always check your milk first for fish, so common was the use of river water to dilute milk. As figure 24 shows the result was a check in the growth of demand, but demand did not go away and consumers instead started searching for imported milk products.

It is not only product safety that becomes a victim of rapid growth. The environment has suffered badly, and many large dairy units have been established with little attention to waste treatment. Indeed one of the most respected milk producers is reported to discharge slurry to a main watercourse. The government appears to be increasingly aware of the environmental damage and whilst there is very limited legislation to address bad practice. Increasingly new proposals are being required to include environmental measures as a condition of development. .

It was the straw shortening development that is particularly credited with leading the green revolution. This simple change meant that a plant would utilise more of its carbohydrates for grain production rather than straw growth. It also had the benefit of allowing greater inputs of fertiliser to maximize yield without the usual risk of the crop lodging (falling flat).

It was the work of organisations such as The International Maize and Wheat Improvement Centre (CIMMYT) in Mexico and The Rice Research Institute (IRRI) based in the Philippines that delivered the necessary innovation. Uniquely, these and other institutions came together in 1971 under the coordination of the Consultative Group on International Agricultural Research (CGIAR). Also critical was the significant increase in the flow of money into. agricultural development World Bank lending alone for agricultural and rural development rose from around 1% of its total lending in 1959 to almost 40% by 1979.

CASE STUDY 8: OBESITY IN THE US

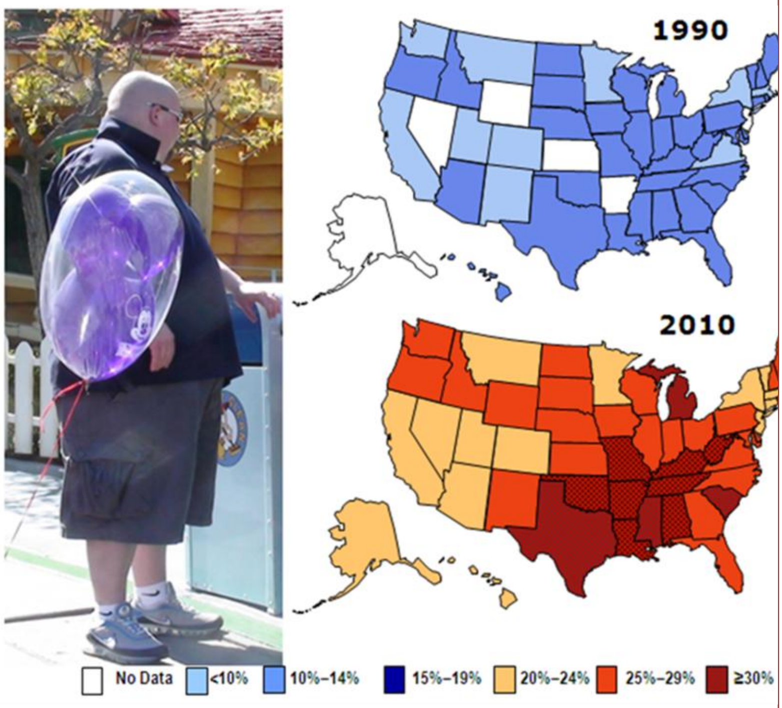

Figure 25: The inequity of calorie consumption, the % of obesity in US adults 1990-2010 (Centre for Disease Control and Prevention)

During the past 20 years, there has been a dramatic increase in obesity in the United States and rates remain high. In 2010, no state had a prevalence of obesity less than 20%. Thirty-six states had a prevalence of 25% or more; 12 of these states (Alabama, Arkansas, Kentucky, Louisiana, Michigan, Mississippi, Missouri, Oklahoma, South Carolina, Tennessee, Texas, and West Virginia) had a prevalence of 30% or more.

5.1.2 THREE SQUARE MEALS

In the most simplistic terms world production is increasing by about 1% per year and demand for food is increasing slightly faster than this as more livestock are also reared. To feed the world we need production increases in the region of 1.5% per year. The success of the green revolution is clear to see. Figure 23 demonstrates how, between 1961 and 1997 the world enjoyed increased food production almost 1% higher than the growth in population. From the early 1960s through to 2007 the gross world food production (cereals, coarse grains, roots and tubers, pulses and oil crops) increased from 1.84 billion tonnes to 4.38 billion tonnes *(FAO, 2009*) which equates to an increase of almost 138%. The increased production per capita helped lift many people out of hunger as well as move many into obesity. In the USA today no state has an obesity level less than 20% and in a number of states it is reaching almost 1 in 3 of the population. Therein lies one of the huge inequities of food production; just because output has increased does not automatically mean it has gone to the most needy.

Between 1961 and 2007 production in Africa rose by 140%, in Latin America by almost 200% and in Asia by 280%. The largest increases have taken place in China where a 5-fold increase occurred between the 1980s and 1990s. In the developed regions of Europe and North America production also increased by 70% and 100% respectively, though it began from a higher starting point (*FAO, 2009*). These increases were, in the main slightly higher than the growth in population. The worry is Africa which is the only region to a have shown a fall in production. The fall began in the 1970s, stabilised within a decade but even today production per capita is only barely back to that of the 1960s. This is largely the result of the fastest population growth in the world combined with a range of political, social and physical problems. Africa is complex, and it is this complication of crop mixes plus lack of access to the resources that are nece, that has left it languishing in the rear.

5.1.3 THE RACE TO STANDSTILL

One source of concern is that we are not sustaining the level of annual production increase that we saw in the last half of the last century. The development of some of our most staple crops is starting to run out of steam. Until recently, one of the world's agricultural jewels has quietly beavered away at agricultural research. Rothamsted Research, formerly known as the Rothamsted Experimental Station, has found itself discussed and cited widely around the world in newspapers and television. The thing that makes Rothamsted unique is it has the world's oldest continuous arable trial, the Broadbalk winter wheat experiment (see case study 9). This 4 acre field in Hertfordshire has recorded the effect of agricultural development on the yields of winter wheat over almost two centuries. It clearly shows the effect of advances such as fertiliser, herbicides and most recently the green

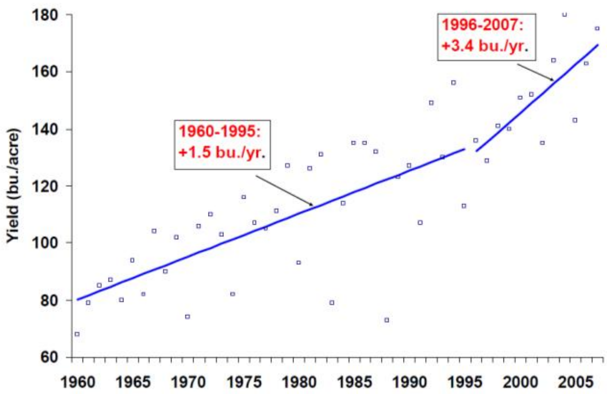

Figure 26: Illinois Corn yields 1960-2007 (Mike Tannura, 2008)

revolution. Professor Maurice Malony, the Director of Rothamsted described an emerging concern; the Broadbalk yields are beginning to plateau. Professor Maloney believes that this is not the result of us reaching the crop's genetic limit but it is more a reflection of the lack of effort in recent years to mobilise sufficient technical development. He points to the examples of corn and soya beans in the USA where yields have continued to improve as a result of sustained efforts to develop new technologies including but not exclusively the use of GM. His assertion is substantiated by data that I was provided with while in Illinois, that not only showed continued improvements in corn yields in the state over the last five decades but also showed that the rate of that improvement had rapidly increased in the period 1996-1997 (*Mike Tannura, 2008*).

Broadbalk is effectively the world squeezed into 4 acres. The unfertilised plots barely giving 1t/ha equate to many of the world's undeveloped regions. The potential is clear: in that if we use the best available technology yields can be increased 10 fold. Those acres also carry a warning for the developed countries: if you take your foot off the accelerator that drives technological development the result is the stagnation of yields that we are seeing today.

CASE STUDY 9: BROADBALK WINTER WHEAT EXPERIMENT

Figure 27: The Broadbalk winter wheat trial (Rothamstead Research, 2006)

Between 1843 and 1856, Sir John Lawes and Sir Joseph Gilbert, two men with considerable foresight, happened on an idea. They realised that to understand the requirements of a crop and particularly its nutrient requirements, they needed to grow the crop continuously on the same site. The plots at Broadbalk were set up to compare the effects of N,P, K, Na and Mg fertilisers in various combinations with organic manures in the form of FYM and rape cake which was later replaced by castor bean meal. The result is the world's oldest continuous agricultural experiment, which has continued with limited adjustments for 167 years.

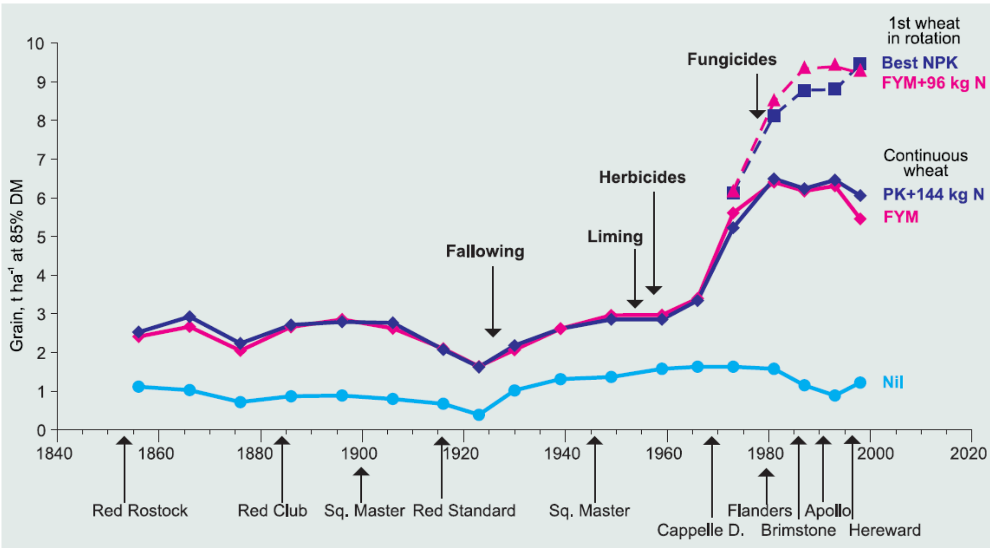

Figure 28: Broadbalk mean yields of wheat grain and periodic changes in husbandry (Rothamstead Research, 2006)

Yields from the plots given no fertiliser or manure (but with pesticides) are typically 1t/ha, virtually the same as they were in 1844. The average yields of wheat provided with P, K, Na, Mg and 144kg of N/ha have always been similar to those given FYM. The effect of the green revolution that swept the world in the 1960s can be seen clearly. By 1968 yields of the new short straw variety 'Cappelle Desprez' were virtually double the previous conventional variety 'Squarehead's Master'. The introduction of higher fertiliser levels in the 1970s allowed full exploitation of the new varieties. This staggering yield increase came to an end in the 1990s when yields began to plateau.

5.1.4 FOOD AFFORDABILITY

Figure 29: FAO food price index 1990-2011 (World Food Situation: FAO Food Price Index, 2011)

At present, 1 billion or just over 15% of the world's population, are hungry. The FAO Millennium Development Goal is to reduce this figure to 8% by 2015. Until recently that looked achievable, with the percentage falling steadily. The number of hungry increased rapidly again from 2006 to 2009 as food prices rose to their 2008 peak and the global economic crisis hit (figure 29). Things improved slightly as food prices retreated from their 2008 peak only to return to an even higher level in 2011. The number of people suffering hunger remains unacceptably high; it now sits higher than it was 40 years ago (figure 30).

Food price increases can be somewhat of a two edged sword, they can deliver higher incomes for farmers lifting them out of poverty and providing money for investment into infrastructure whilst, for the most vulnerable, they can simply reduce their access to food unless special measures are provided to protect them.

The impacts of high food prices are expected to become a bigger feature of the future. The 'Foresight Project' team commissioned the International Food Research Institute (IFRI) to examine whether the recent price increases were simply short term volatility because all volatility is not new and was frequently a feature of food prices in the 1970s. The IFRI set up a series of economic models examining a range of future scenarios. Corn (maize) accounts for the largest share of the world's crop production. The IFRI modelling predicted that even before the effects of climate change are accounted for, corn prices will increase by 40% in real terms by 2050. When climate change was factored in price increases were almost double. Economic models always require cautious interpretation but since the IFRI model was generated other organisations have published their own results which are broadly similar. Such high price increases as those now being forecasted will have a significant effect on even high income regions of the world; their impact could be devastating for the poorest consumers.

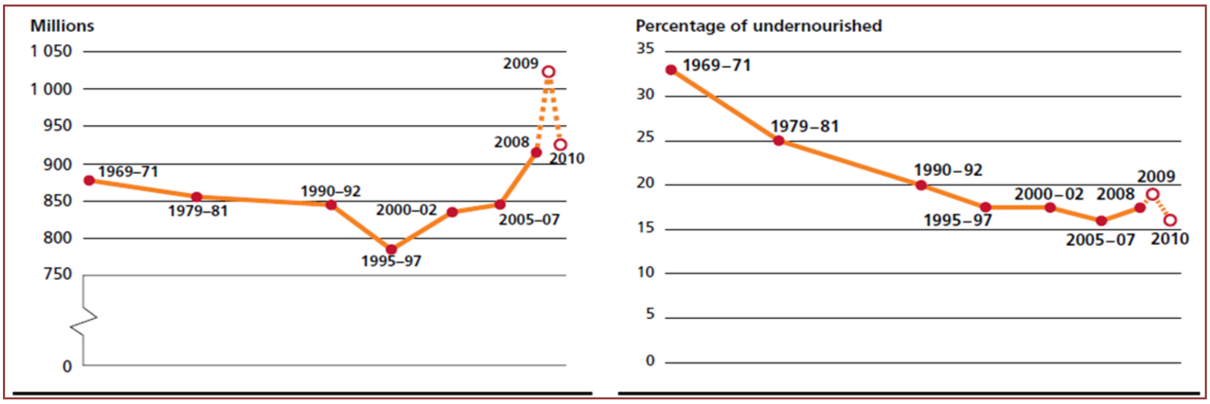

Figure 30: Left: Number of undernourished people in the world 1969-71 to 2010. Right: Proportion of undernourished people in developing countries, 1969-71 to 2010. (Food and Agriculture Organisation, 2010)

5.1.4 THE SEARCH FOR THE SMOKING GUN

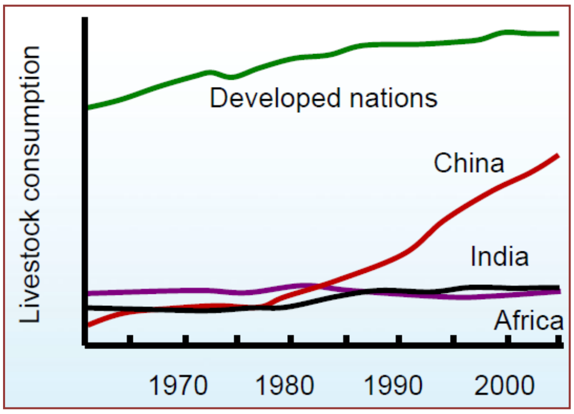

Figure 31: Livestock consumption based on FAO data presented by Professor Charles Godfrey. (Godfrey, 2011)

In 2008 world food prices peaked at unprecedented levels, and this was repeated at even higher levels three years later, following a period of almost 40 years of historically low food prices. Today, we are seeing not just high prices but levels of volatility that were not a feature of the past. The first reaction of many was that high prices were the result of rising demand from rapidly developing nations. As individual wealth increased, particularly in China and India, there was a shift to a more western diet. While this is partly true it is by no means the main driver of food price inflation. The assumption that increasing wealth will automatically result in increased animal consumption also as to be treated with caution because cultural, religious and socio-economic factors can have considerable influence. If you take people of equivalent wealth in China and India for instance it will be the Chinese that are more likely to be embracing a western style diet. This point was demonstrated to me by Professor Charles Godfrey who chaired the Foresight Project's lead expert group. Using data from the UN Food and Agriculture Organisation (FAO) Professor Godfrey demonstrates the marked difference in livestock consumption between India and China (figure 31).

There are many theories over the cause of the recent food price spikes. The story begins in 2000 when global grain stocks began to decline. Stocks at the turn of the century typically equated to 110 days of food, but by 2004 this had dropped to 60 days (*Trostle, 2008*). Today despite year on year increases in production total grain stocks remain at a similarly low level (see figure 32).

The main reason for the fall in global stocks is that demand is exceeding supply, this situation was a result of policies in part designed to reduce the expense of holding large food stocks. At the same time the US

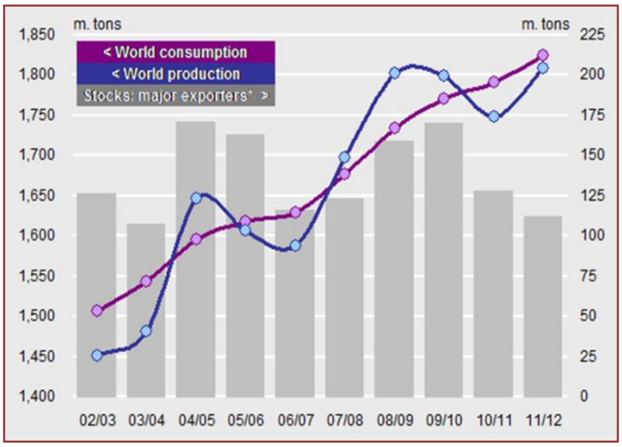

Figure32: World total grains production, demand and stocks (International Grains Council)

dollar began to weaken resulting in higher oil prices, a trend which accelerated in 2004. The result was that the economics of biofuel production, particularly US bio ethanol which also carried significant government subsidy, diverted large tonnages of grain away from the food chain. By 2006 investors had also discovered the soft commodity market as a way to diversify investment portfolios away from investments which were then at the mercy of the global economy. Analyses carried out at IFPRI *(Bryce Cooke, 2009)* suggest that while the activities of speculators were not the only responsible factor, they were a very significant one. None of the other factors alone could explain the increase in agricultural commodity prices by a multiple of two.

CASE STUDY 10: A SUMMARY OF EXPLANATIONS FOR THE RISE IN AGRICULTURAL COMMODITY PRICES

FACTORS	MECHANISM
Rising world demand	Emerging nations can afford more diversified food consumption. Demand for direct consumption is increased alongside demand for use in livestock feeds
Ethanol/Biofuels	Greatly increased use of grains diverted from the food chain
Increased activity in the futures market	An increasing proportion of the market place has no intention of taking delivery of futures, increasing short term volatility
Increasing oil/fertiliser prices	Higher production costs limit output
Low level of investment in agricultural R & D	Reduced research results in a fall in the growth of agricultural output
Trade barriers/export restrictions	As some countries sought to protect their domestic production from being sold for export the liquidity of supply was restricted
Droughts	A series of weather events disrupted production in some of the most strategically important grain producing regions
Dollar weakening	Most commody indicator prices are quoted in US dollars

Figure 33: Summary of food price drivers adapted from (Bryce Cooke, 2009)

6.0 RESOURCE LIMITATIONS

Summary

The rapidly increasing population of the planet has an insatiable demand for finite and diminishing resources such as land, which we are losing at something in the region of 470 hectares an hour. There still remains a small amount of land to press into production but this only equates to the same area that will be lost by 2030. The result is that we need to learn to produce a lot more from a smaller resource base. It is also clear that there needs to an awareness that the sensitivity of land tenure will increase in correlation to the pressure to produce food and unless this is addressed we risk political and social unrest of the type seen in Zimbabwe.

6.1 THEY'VE STOPPED MAKING LAND

Alongside innovation based production improvements there has been an increase in the amount of land being cultivated. For many years land was the main source of increases in production. Between 1927 and 1960 the amount of forest and prairie being cleared to create agricultural land was still significant and land under cultivation increased from 1 billion to 1.4 billion hectares (*Trostle, 2008*). Since 1960 the amount of land being brought into production has reduced, and between 1980 and 2000 most of the new land coming into production was confined to the tropics; more than half was at the expense of virgin forest and a further 28% from previously disturbed forest (*Eric Lambin, 2011*). It was this that generated increasingly loud calls for the protection of rich sites of biodiversity and caused increasing attention to be paid to intensification in a sustainable manner in existing areas of production. Today, the fact that conversion rates are reducing is largely now offset by the urbanisation and degradation on existing land.

Land Use Category	2000: million hectares	2030: additional million hectares
Cropland	1,560	114
Pasture	2,955	76
Natural Forest	3,507	
Planted Forest	171	83
Urban	209	74
Unused farmland	401	
Biofuel		81
Expansion of protection areas		53
Lost to degradation		59
Total	8,803	540
Difference excl unused farmland		139

Figure 34: Estimate of land use in 2000 and additional demand in 2030. The data has been simplified from the original source (Eric Lambin, 2011)

Determining the amount of potential and available land for agriculture is notoriously difficult and unreliable not least because of constant change and difficulty in defining suitable land, given changing levels of degradation, urbanisation and restoration.

One attempt to summarise the situation from a range of expert sources is presented in figure 34. The table is based on average values taken from a range of estimates and scenarios and in some cases the variations contained in them are very significant.

The main point to note, however, is that of the total land on the planet which is ice free (13,300 Mha) only about 4,000 Mha is suitable for rain fed agriculture. The estimates of the amount of non-cultivated land area that is suitable for cropping and is not forested, protected or populated varies from 356-445 Mha. This land is mostly found in Latin America's cerrados and grasslands (Brazil, Argentina) and in the African savannas (Sudan, Democratic Republic of the Congo, Mozambique, Tanzania, Madagascar). Although these areas are not forested the conversion of this land will not be without some environmental impact as many of these areas are rich in biodiversity.

The collapse of the Soviet Union also resulted in the abandonment of 26 Mha of farmland (Russia, Belarus, Ukraine, Kazakhstan). Whilst this is progressively being regained and pressed into production it is not without difficulty as the case study featuring Landkom in the Ukraine demonstrates.

There are many different land uses competing for all available land and it has been calculated that to feed a growing world population requires an additional 2.7-4.9 Mha of farmland per year. The actual amount depends on a huge number of variables, including future diets, the reduction of food wastage, yield improvements, environmental protection policy and biofuel policy.

In 2007 the world's newfound appetite for biofuels required 25 Mha. If existing mandates for the continued substitution of petroleum based fuels with biofuels continues then biofuels alone will require an increase of 1.5-3.9 Mha per year.

Losses of land to urbanisation will also continue and are predicted to be in the region of 1.6-3.3 Mha per year; unfortunately though this tends to be disproportionately some of the world's highest quality agricultural land.

Pasture areas are generally not expected to increase or to do so at a relatively slow rate 0-5 Mha per year. The expansion in livestock output is expected to be met through greater intensification but indirectly this will also require additional land for feed production.

Protected areas are expected to expand by 0.9-2.7 Mha per year and land degradation will reduce the capacity of land to produce, making a total of 1-2.9 Mha unsuitable for cultivation each year.

If average values are taken as shown in figure 34, the additional land requirement by 2030 will be 540 Mha. Of this total 401 Mha of unused farmland can be brought into production leaving a shortfall of 139 Mha. Bearing in mind that population growth is not expected to stabilise until 2050 it is probable that additional land availability alone will not be enough to meet food needs. Allowing for the variable predictions the land reserve could be exhausted as soon as the late 2020s or as late as 2050. Whichever is the case it is clear that additional means of increasing food production need to be pursued in parallel with land developments if we are to avoid resorting to deforestation and the destruction of natural areas of high biodiversity.

6.1.1 THE GLOBALISATION EFFECT

Global land availability is made more complicated by the effects of economic globalisation which has seen a spate of large scale land transactions carried out by international corporations and even governments. There are mixed thoughts over what is taking place. Over a coffee in the outskirts of Nairobi, agri-business investment consultant Emma Cardy-Brown talked about the huge range of projects and investors that are lined up to work in Africa.

The most critical factors that allow projects to take place are infrastructure and land title. The ability to secure some form of 'hardcore' varies from country to country; in parts of the world like Brazil, where title is assured, investment appears more attractive than in a country like Tanzania where the socialist history has left all land in the ownership of the government. It is difficult to get land released for development.

CASE STUDY 11: LANDCOM, UKRAINE

At 42 Mha the Ukraine has the largest agricultural land area in Europe, of which 32 Mha is arable, but only 25 Mha is in production. The agriculture sector in Ukraine has gone through a period of considerable transition since the country achieved independence in 1991 following the break-up of the Soviet Union. State and collective farms were officially dismantled in 2000. Farm property was divided among farm workers in the form of land shares and the majority of the shareholders leased their land back to the newly formed private agricultural associations. Over the subsequent decade following independence, fertiliser usag fell by 85% and grain production declined by 50%. Landkom is the largest farming operation in the Ukraine; the company operates from 3 main areas, West, Central and Southern Ukraine.

The CEO of the company, Vitaliy Skotsyk, describes how the Ukraine has the some of the best soils, and that of the 32 Mha of arable land, 28% comprises some of the richest, deepest black soils in the world. The company holds leases on 74,000 hectares of land and in 2010 it cultivated 39,000 hectares to produce 96,000 tonnes of crops.

Landkom, like the rest of the country, is an example of potential not being realised. Despite access to some of the best soils in the world and a climate more than capable of high yields, the current average wheat yields are 2.4 t/ha, Vitaliy suggested that with the correct agronomy potential yields should be 6.0 t/ha.

Despite a land bank of 74,000 ha the company like the country was unable to resource production on more than 39,000 ha. Vitaliy explained to me some of the restrictions on production including very limited infrastructure and access to western quality technology. Access to agronomy expertise in the country is limited so the company employs consultants directly to ensure access to high quality agronomy advice. Perhaps the most limiting factor is the lack of storage and transport capacity. In a country of only 3 million people the domestic market is negligible and therefore export capability is critical.

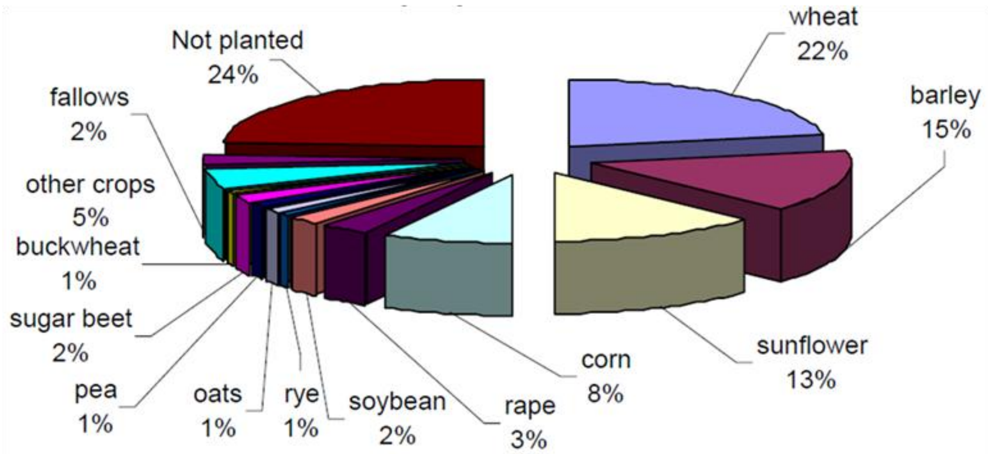

Figure 34: cropping distribution in the Ukraine, 2010

CASE STUDY 10: LANDCOM, UKRAINE

The country has an immediate shipping capacity of 24 million tonnes and a storage capacity of 18 million tonnes. Production in 2010 was 40 million tonnes, and if production was increased much beyond this there simply would not be the capacity to deal with it. There are currently 11 Ukraine ports capable of dealing with exports, 2 were completed in 2010 and another 3 are currently under construction. The same lack of facilities applies to fertilizer. While Ukraine is 100% sufficient in Nitrogen production there is a lack of capacity to create compound blends.

One of the most striking examples of the lack of infrastructure is that it is estimated that 50 million tonnes of grain was left in the field in 2010. Across the country there are 47,000 combines but only 7,000 are relatively modern western machines whilst the remaining 40,000 are ex Soviet machines that are at least 25 years old. Typical in-field losses from these geriatric machines are anywhere between 25-40%.

Vitaliy estimated that the investment required to bring land into production in terms of both operating costs and Capex is typically $1,200/ha. Most farms have access to only $100/ha meaning that less than 10% of land is working to full capacity. To equip the country to maximize production would equate to $20 billion but would potentially raise national output to 120 million tonnes/year.

Figure 35: Ukrainian combines date predominantly from the Soviet era

All too vivid for many potential investors is the experience in Zimbabwe, a country which was considered to be the agricultural jewel in the African continent. It was so successful was it that it was air freighting mangetout to UK supermarkets in the 1980s. Today it is wracked by famine and poverty, largely the result of a change in land policy. Many of those that I spoke to in Kenya could not rule out such an eventuality befalling their country, so emotive is the land tenure issue in Kenya and many other African nations.

Already in Kenya there is a draft piece of legislation to remove the 999-year leases that were granted to many foreign estates at independence in 1963 and to replace them with 99 year leases. This would apply to land held by non-Kenyan residents. For a country in such desperate need of foreign investment and job creation (50% unemployment) such proposals should be economic suicide in terms of investment confidence, but so emotive is the issue of land that for some politicians it is a sure fire vote winner.

A high level of corruption and nepotism in many African states also does little to help investors realise the potential of land, unless they also want to play the game. In many African countries the mechanism is ‘Chi’ (Swahili for tea). Chi is a colloquialism for a bag of cash passed below the table to oil the wheels of trade.

Many international corporations and governments are looking at regions such as Africa and South America as a strategic means of securing food production capacity. Each brings a different level of probity and undoubtedly many play the ‘Chi’ game to secure their interests.

The presence of foreign investors has variously been described as a land grab and as economic development. The truth is somewhere in between. Certainly there are examples of questionable practice. I came across one example in Zambia where a Chinese company had established a large scale farming operation. The company imported not only all of its equipment but also its entire staff, from management to labourers, from China. In turn the product from the farm was exported back to China. So much resentment was created that it spilled over into violence and the murder of a Chinese lorry driver.

When Zambians went to the polls in September 2011, the Chinese question was the single biggest issue. The incumbent party of President Bande, whose campaign was rumored to be funded by the Chinese supported continued Chinese investment in the country. To date, investment by China in Zambia’s copper industry has exceeded $1billion with a further $5 billion proposed, yet a very small percentage of this has cascaded down into agriculture or the reduction of poverty. 66% of all Zambians have a daily income below the official definition of poverty of $1.25/day. The challenger and victor in the elections was Michael Suta, the one time London bus driver, who claimed that the Chinese were ‘taking over’ Zambia by exploiting its natural resources and workforce; his election would seem to suggest that the country agreed.

In 2009 over 50 Mha of farmland in Africa had been the subject to known negotiation or transactions of the type described in Zambia (*Friis A, 2010).* Most of the investors involved were oil or capital rich companies or countries from Asia and Arabia. The food or biofuel produced on these farms was destined for export to the investing countries.

International land transactions are perhaps one of the biggest impacts from globalisation of agriculture. They have been encouraged not only by increasingly scarce resources, but also the globalisation of trade, liberalisation of land markets and the scramble by foreign investors to gain exposure to the booming agricultural sector rather that other sectors currently caught up in the global downturn.

For foreign investments to work in developing countries a sense of ‘Corporate Social Responsibility’ (CSR) is needed. The reality is that there is rarely any entirely bare land in the world. It may be underutilised but it will rarely be unoccupied. Foreign investment and use of the land in these areas can be a force for good. Indeed, in many parts of Africa I have met people with no motive other than the improvement of the lives of people who were keen for foreign investment. Most would have preferred it to come from the West, but in its absence they were looking eastwards.

Talking to both European companies and institutions there seems to be a perception that to invest in Africa is wrong. Far too much has been made of the land grab issue to the point that many of the more reputable organisations are worried about the impact on their reputations, whereas the right type of investment, together with a strong CSR component, can be an incredible force for good as in the case of Oserian (case study 3). Both NGOs and government development departments should consider greater encouragement for the correct form of investment into many developing countries.

6.1.2 THE PASSION FOR LAND

Land is an incredibly emotive subject in every part of the world I have visited. So entwinedare we with the land that it is frequently the source of tension and disagreement between families, communities, and even countries. So primal is the need to have our own piece of the planet that people are willing to ignore the law, abandon ethics and in some cases resort to violence to secure it.

In Kenya this is particularly the case. There has been a squatter problem in many parts of the country ever since the Supreme Court declared Africans as Tenants at Will of the Crown following the promulgation of the Crown Lands Ordinance of 1915. The problem of landlessness was never resolved. The dispossession of many Africans from their. lands meant that only a massive resettlement programme could provide a solution. However, the negotiations for independence extracted guarantees from the new independence government that white farmers who wished to remain in the country would retain their land.

The government was unable at the time to deal with the landless through resettlement or redistribution of land, and instead the newly independent government introduced a policy called the 'Settlement Scheme'. This was based on a free market system requiring a willing buyer and willing seller. Many of the most needy were left out of this programme, and it became a means by which the middle classes and political elite could take advantage of the poor to accumulate large parcels of land. Today, one of the largest landowners in Kenya continues to be the family of Jomo Kenyatta, the country's first President at Independence. His extended family are reputed to own over 500,000 acres of some of the best land in the country. Overall, more than half of the country's best arable land lies in the hands of only 20% of the population (Otsieno Namwaya, East African Standard, 2004)

Thus the colonial land legacy continued and, in many parts of Africa, is intensifying as a result of higher food prices and rapid population growth. I obtained a small insight into how this passion can materialise and how, through innovative measures, it can be turned around to contribute to sustainability (see case study 12).

Throughout much of Africa there is a romantic notion, often promoted by NGOs, that everyone should have access to a piece of land to carry out a form of subsistence farming. While for many this will be a useful solution it should be remembered that through history there are no examples of countries economically developing to the point where poverty is removed without agriculture undergoing rationalisation and the amalgamation of land holdings. To allow the continued subdivision of holdings does little more than condemn families into continued poverty.

CASE STUDY 12: THE GACAGI SELF HELP COMMUNITY EXPERIMENT

Figure 37: Mud hut in the existing slum, home in some cases of up to 10 people

The Kakuzi company is based a few miles outside the town of Thika in the Kenyan highlands. The company owes its origins to a sisal production estate which, during the 1920s, was expanded to over 40,000 acres through the purchase of other hill farms growing coffee. Today, the coffee and sisal have been replaced by macadamia nut, tea, avocados, pineapples, beef and forestry. The company is responsible for 75% of all Kenya's avocado exports and is owned by UK based Camellia Plc.

As a large foreign owned estate it is often the focus of debate over land use and ownership. Currently there is contention between certain political and community elements and the company over the suggestion that it should give up a significant area of land for the creation of a road scheme. Local MP, Elius Mbau, who has tabled the matter before parliament claims that unless the road is built rising tensions will result in violence; there is obvious danger that such suggestions from an elected official risk becoming a self fulfilling prophecy.

Also subject to debate in Parliament has been the issue of squatters, or the landless, as politicians prefer to refer to them, on the Kakuzi estate. For over 30 years a group of 35 families representing 415 individuals has illegally occupied an area of about 1 acre on the estate. The families live in appalling conditions with, in some cases as many as 10 people living in mud huts smaller than a single garage. Water for the families on the squat and for many others for some distance comes from a single spring which runs year round, but at barely a trickle, and is open to contamination from animal and people activities. The squatters get by any way they can by labouring on the nearby farms or by less legitimate means. For many years there has been tension between the squatters and Kakuzi. After decades of impasse the squatters continued to be locked into a squalid existence and the company continued to be associated with an issue that always threatened to tarnish the company or provide a cause for agitators.

Kakuzi has chosen a radical experiment to break the deadlock. The CEO of Kakuzi, Richard Collins, described to me the philosophy behind the decision. In Kenya, land is often subdivided as it passes from generation to generation and often split between several siblings. The result is that families are trying to survive in some cases on as little as 1/8th acre of land which condemns these families to poverty. Richard says, "To help people in poverty we need to be clear of our objective. Do we want them to survive or thrive? Survival locks them into poverty, but if they thrive their children go to school and they can access things like healthcare". It was by using this philosophy that Richard determined that a family needs 1 acre to thrive. The radical element was the decision to give each of the 35 families in the squat the chance to build a home on 1 acre. It was a bold move which,as Richard puts it, "Could be a spectacular success or an unmitigated failure that would create a bigger problem, a 35 acre slum"

CASE STUDY 12: THE GACAGI SELF HELP COMMUNITY EXPERIMENT

To avoid the risk of failure the company has signed a memorandum of understanding (MoU)with the families that make up the community. The MoU sets out the terms and conditions by which the land is provided. The title deeds remain with Kakuzi, and the community must create a committee to represent them plus appoint a Chairman and Secretary who will maintain a detailed census of the people in the community and the name of a head of the household to whom the land will be given. The head of household must nominate a successor to the land in the case of his death. A key feature of the agreement is that there must always be only one successor on the record in order to avoid the risk of subdivision of the property. No holding will be allowed to fall below 1 acre.

Each of the plots is being created on an area that was previously commercial forestry. The plots are laid out by the company according to a standard design based on a house surrounded by a kitchen garden, an external toilet block and set areas on the plot for animals and certain crops. The model is taken from the successful design and layout adopted by the company for their own house provision for their staff. Key, though, is that the community must build its own homes according to the agreed design, and the company's engineer oversees and provides advice and has even provided the loan of a brick making machine for their use. Only when each 2 or 3 homes is completed to the required standard are another 2-3 smallholdings released. Currently, the first 2 houses are complete and 2 ladies, both in their 70s, have been moved in. Within the first year the holdings have been planted and have yielded so much excess product in the form of tomatoes that the family has been able to sell the surplus, realising 200,000 Kenyon shillings (£200), a small fortune in their terms. The second phase of 3 further smallholdings is almost complete, and the community is keen to start on the next 6 smallholdings.

The step change for these families involved cannot be overstated. In their wildest dreams they could never have imagined having such a large piece of land, and few have much experience of building or farming so the learning process is considerable. The critical factors to the project's success will be the individuals involved. The ability of the Chairman and his Secretary to speak for and control the community is critical and the ability of the Kakozi staff to both control and advise the development. To facilitate this the company has provided input from their engineer and a sustainable farming consultant who visits the community. The greatest symbol of the huge step change has to be the example of Ed the head of Kakuzi security, an ex-army officer who oozes an air of authority tempered with a big smile, and Humphrey, the Chairman of the community, a quiet and slightly shy man. For years Ed and Humphrey rubbed against each other as Ed tried to clamp down on the illicit alcohol that Humphrey sold around the estate. Today the two old gentleman walk comfortably together through the new smallholdings discussing plans.

Figure 38: The team making things happen. Left to right Gregory Colemba (Secretary) Ed "Captain" (Kirkuzi Head of Security), Humphrey Ngaria (Chairman) and kneeling David Migot (Kikuzi Engineering Manager) pictured in front of the first smallholding to be completed.

7.0 NUTRITION

Summary

Nutrients are one of agriculture's most important resources but they are also one of the main contributors to the un-sustainability of the industry. Whilst it is non-finite, nitrogen fertiliser depends on the use of huge amounts of fossil fuels and its production is responsible for a very significant part of agriculture's greenhouse gas emissions. Phosphate reserves are significantly greater than is often reported but those reserves will only come to market at a significantly higher cost than has historically been the case. There are huge excesses of Nitrogen and Phosphorus circulating within the environment which, with the correct stewardship and technology, could be used to displace fossil sources.

7.0 NUTRIENTS

Nutrients are the foundations on which modern agriculture has been built. The Broadbalk plots at Rothamsted, noted earlier, demonstrate just how critical they are. The treatments receiving optimum amounts of nutrients out perform the unfertilized plots ten fold.

As valuable as nutrients are however, their use has been at considerable cost to the environment and in some cases human health.

7.1.1 NITROGEN

The value of nitrogen to agriculture has long been recognised but, despite the fact that nitrogen in its gas form constitutes 78% of the air around us, it occurs in only very limited amounts naturally in the reactive forms that allow it to be utilised by agriculture. Until the early part of the 20th century the only supplemental forms of nitrogen available to farmers were based on the capacity of legumes in a rotation to fix atmospheric nitrogen and small deposits of fossil nitrogen contained in bird guano, coal and saltpetre.

At the turn of the 20th century the Haber Bosch process was developed to convert atmospheric nitrogen and hydrogen into ammonia. This paved the way to the mass manufacture of cheap inorganic nitrogen and suddenly the principal limiting factor of crop production was removed. In 1900 global farming was able to produce sufficient food for 1.6 billion people from 850 million hectares, farming was extensive and artificial fertiliser was yet to feature. The same practices, together with the larger available area of 1.5 billion hectares would today sustain around 3 billion, nearly half the global population.

The benefits have been huge not only for livestock and crop production, but also further down the food chain because of the shift to low cost food with a more secure supply chain. In Europe it is estimated that the benefit of nitrogen fertiliser to the EU wheat crop alone amounts to €8 billion. Synthetic fertilise, N, has been estimated to be responsible for the production of 50% of the world's available sustenance *(Smil V. , 2000)*. Counter to this however there are many negative effects from N on human health and the environment. Agriculture in particular has relatively low nitrogen utilisation efficiency; this is especially the case where higher application rates are common practice. The end result is large amounts of reactive nitrogen being deposited into the natural environment.

Nitrogen pollution comes from a complicated set of interactions and mechanisms. Agriculture's contribution to this is principally through gaseous emissions and leaching loss

(N_2, N_2O, NO, NH_3). In a summary for policymakers the European Nitrogen Assessment (Sutton M A, 2011) sets out the five principal environmental threats from agricultural nitrogen losses:

1. Water quality: Reactive forms of nitrogen cause eutrophication and acidification of freshwater bodies, estuaries and coastal regions. High nitrate concentrations in drinking water are also considered to present a risk to human health.
2. Air quality: Air pollution is created principally through ammonia emissions both from organic fertilisers, intensive livestock operations and crop losses through volatilisation of fertiliser.
3. Greenhouse gas: nitrous oxide (N_2O) is a greenhouse gas 296 times more potent than carbon dioxide. Additionally it contributes to stratospheric ozone depletion. Emissions arise as a result of the de-nitrification of both livestock manure and inorganic fertilisers applied to soils.
4. Ecosystems and biodiversity: Atmospheric nitrogen deposition in sensitive ecosystems can encourage the domination of plants and micro-organisms that favour high levels of available nitrogen and acidic conditions. At particular risk are those habitats adapted to low levels of nutrient availability such as native grasslands.
5. Soil quality: High levels of nitrogen application to soils results in acidification.

The use of reactive nitrogen in agriculture has brought huge benefits to mankind. It contributed to allowing the population to increase massively in the last century, has brought economic, social and health benefits and has even brought about political stability in many parts of the world. This has only been achieved by mankind making massive changes to the natural nitrogen cycle.

The amount of atmospheric gaseous nitrogen that has been 'fixed' into reactive nitrogen forms has been doubled globally and tripled in Europe, from the levels achieved naturally before 1900. All of this additional reactive nitrogen coursing through the environment presents many opportunities for leakage in forms that can contribute to the environmental problems described above. The 'Amm2Fert' project described in case study 13 has the potential to set up detours within various pathways to convert and re-route forms of nitrogen that would previously have leaked from the system back into opportunities to not only utilise it but to displace new reactive nitrogen . The system is a means of maximising the benefits of nitrogen by increasing the efficiency and optimisation of its use.

7.1.2 THE SEARCH FOR NITROGEN FERTILISER

Farmers up until the 19th century adopted three mechanisms by which they could introduce plant nutrients to crops:

1. Recycling: Nutrients taken up by plants previously were returned to the soil through the application of crop residues, human and animal manures and animal derived materials such as blood and bone material.
2. Relocation of nutrient: Material from other areas containing nutrients such as woodland litter or seaweed could augment nutrients though this also risked depleting them from other ecosystems.
3. Fixation: Legume plant species are able to use rhyzobial bacteria residing in root nodules to convert gaseous nitrogen into reactive forms. The disadvantage in many cases was that land was often unavailable for food production while legumes were growing to fix nitrogen for subsequent crops.

Through the 19th century alternative sources of nutrients became available in the form of mineral fertilisers.

- Gas lighting initially was based on the use of coal gas. The gas contains up to 1.5% ammonia, precipitated as sulphate of ammonia which contains 21% nitrogen. Availability was limited by gas production.

- Sodium nitrate was produced in Chile, Peru and Bolivia where the sodium nitrate could be washed out of the naturally rich soil layers using hot water. The leachate was subsequently purified and dried. Production peaked in 1930 at 3 million tonnes per year.
- Between 1840 and 1875 there was a dash to exploit fossil deposits of bird manure, or 'Guano' that could be as deep as 60 metres and were also a rich source of phosphate. The reserves were completely exhausted in only 35 years.

The loss of Guano meant that agriculture was reliant on by-product sulphate of ammonia and Chilean nitrate and so the race was on to develop technical solutions.

- At the end of the 19th century two chemists Frank and Caro found that at 1,000 to 1,100C calcium carbide combines with gaseous nitrogen to form calcium cyanamide. Commercial plants were built in Italy and Germany until 1908 though the process was heavily reliant on cheap electricity.
- The natural phenomenon by which N2 in air is converted to nitric oxide (NO) by lightning was replicated by Norwegians Birkeland and Eyde, and by 1913 three plants based on this system were operating in Norway

The limitations of these technical solutions were that they demanded huge amounts of cheap electricity, so there was a need to continue searching for more efficient sources of nitrogen.

As a professor of Chemistry at the University of Karlsruhe in Germany, Fritz Haber, understood that ammonia broke down into its component parts of hydrogen and nitrogen at high temperature, and he set about looking at ways to reverse this mechanism. Haber discovered that by using an osmium catalyst together with high pressure (175-200 atmospheres) and temperature (550-600C) he could convert gas mixtures to ammonia. Haber contacted German chemical company BASF who assigned a young chemist Carl Bosch. The process was industrialised and the first pilot plant was established in 1913. Today, 99% of all artificially fixed nitrogen is produced using the Haber-Bosch process. Natural gas has become the preferred source of the hydrogen with the nitrogen component still being taken from the air. It has been estimated that globally the manufacture of

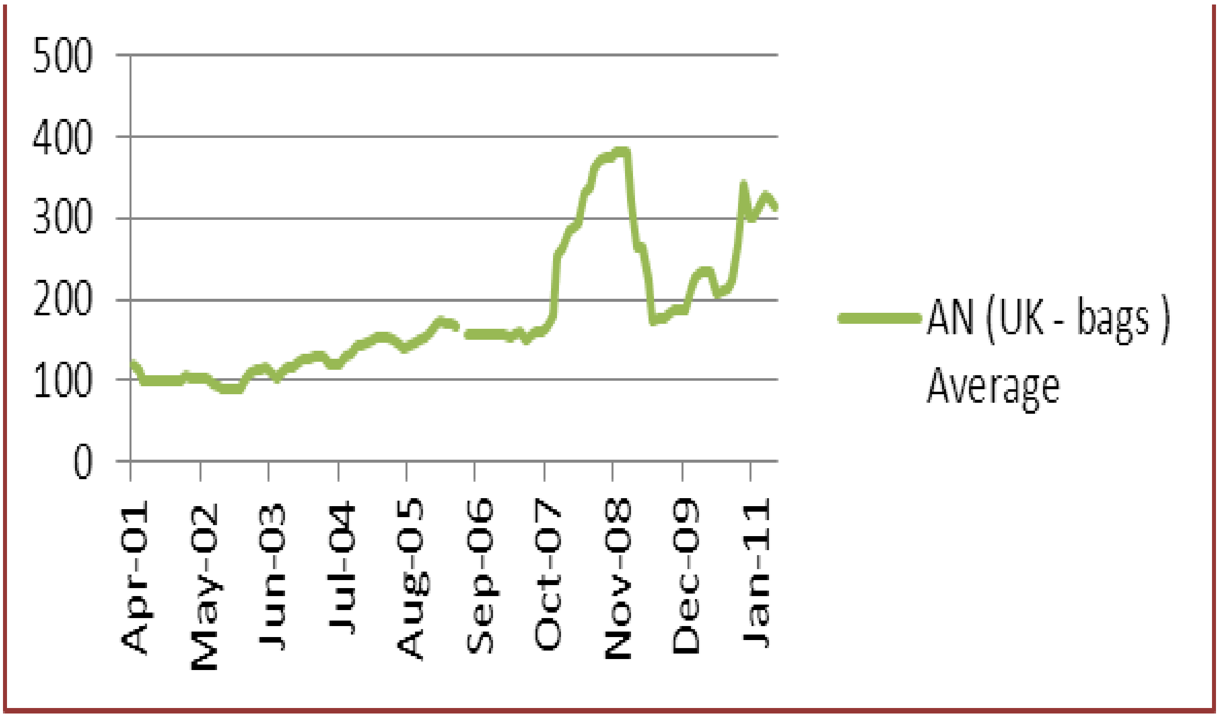

Figure 39: Price volatility of Ammonium Nitrate fertiliser (expressed in £/tonne) (DairyCo, 2011)

nitrogen fertilisers uses 5% of the world's annual natural gas consumption and 2% of world energy (Smil, 2001).

7.1.3 FERTILISER COST

Fertilizer prices and demand have historically been influenced by changing and often interrelated factors such as population, economic growth, agricultural production, government policy and food costs. These continue to drive the price and demand for fertiliser to this day.

The last few years have been characterised by huge increases in many commodity prices and this has certainly applied to fertiliser and feed and food . The increases have been partly fuelled by significant rises in demand from not just the more traditional sectors but from other markets which traditionally had little linkage with the agricultural commodity markets including the energy sector which has become a significant buyer of agricultural commodities.

Figure 39 demonstrates the volatility that has characterised the price of ammonium nitrate fertiliser in the UK in recent years. Supply and demand issues have already resulted in the 2011/12 fertiliser market season opening with higher prices than had been previously forecast. The sharp price increases seen recently take fertiliser costs to the levels last seen in 2008. There have been a number of factors which have resulted in reduced production in parts of the world. A scarcity of gas in Egypt, and Pakistan and Bangladesh have seen supplies diverted from fertiliser manufacture. The expectation that China would resume large scale exports has also failed to materialise. The impact has been the sharp upward movement of fertiliser prices recently with urea alone rising by $80/t in two weeks. Most predictions expect the market to remain bullish and volatile.

CASE STUDY 13: AMM2FERT, HARPER ADAMS UNIVERSITY COLLEGE, UK

The ‘Amm2Fert’ project has the potential to set up detours within various pathways to convert and re-route forms of nitrogen that would previously have leaked from the system back into opportunities to not only utilise it but to displace new reactive nitrogen

This project will use an innovative method to manufacture ammonia based fertiliser products using a combination of an advanced biochemical reactor technology and a novel enzyme enhanced biochemical process for ammonia release. The project involves the novel use of a down flow gas contactor technology (DGC) developed by WRK in a three stage process to strip ammonia gas from livestock slurry produced at Harper Adams University College and to efficiently convert the ammonia gas through acid neutralisation into inorganic fertiliser in the form of ammonium nitrate.

The process once developed will be equally applicable in the first instance to all forms of intensive livestock farming. If successful the process has the potential to be deployed further afield in areas such as the food processing sector anaerobic digestion and effluent treatment. The project will develop a novel process that will allow the commercial scale on-farm recovery and utilisation of ammonia for the production of a sustainable, resource efficient, low cost, low carbon footprint fertiliser product. The consortium is building on existing world class knowledge in UK sustainable agricultural practices and farming diversification.

The objectives of the project are to:

- Prove the concept of ammonia based fertiliser production through the efficient recovery and utilisation of on farm resources i.e. ammonia-containing slurry.
- Evaluate the use of the sustainable fertiliser products in terms of benefits in cost, improved environmental impact, and improved nutrient management, reduction in storage, transport and spreading costs.

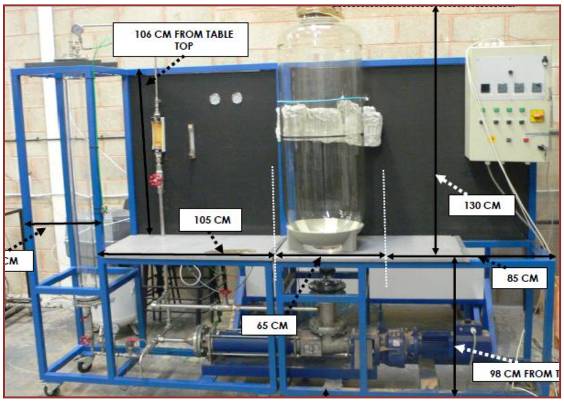

Figure 40: Lab scale development of the Amm2Fert project at Harper Adams Farm

The system is a means of maximising the benefits of nitrogen by increasing the efficiency of use of nitrogen in order to better optimise its utilisation.

CASE STUDY 14: NITROGEN FERTILISER ABUSE IN CHINA

China has a problem; it has too many nutrients. This is not normally a problem unless, as in China, they are in the wrong place. Excess nutrients in the environment are causing acidification of soils and over the last 20 years soil ph has dropped by 0.5 (*Zhang F. , 2011*), and eutrophication is widespread affecting 60% of all watercourses (*Zhang W. , 2011*),. Fertiliser alone is responsible for between 6-8% of China's greenhouse gas emissions.

China is the biggest producer and user of nitrogen fertiliser in the world and that trend continues to grow, in contrast with many of the developed countries where its use has stabilized or is even falling. In the last 20 years China contributed to an increase of 60% in world nitrogen usage. In 2010 China used more than 64 million tonnes of N, P and K fertiliser across a wide range of enterprises including not only cereals but also cotton, oil crops, vegetables, fruit, aquaculture and tree production, including lacquer trees, rubber and bamboo.

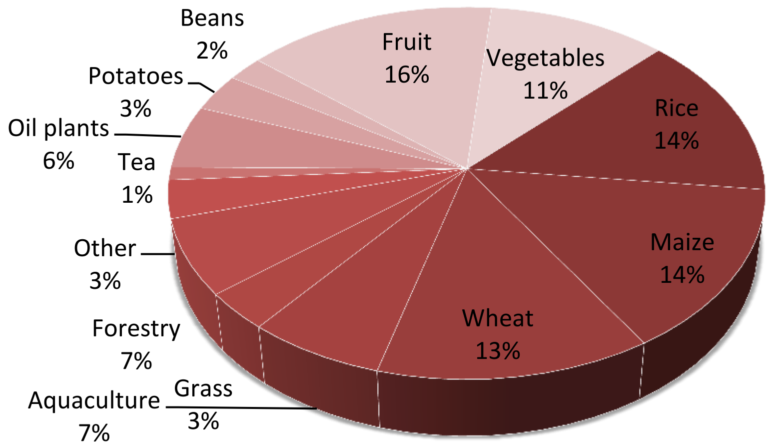

Figure 41: The distribution of nitrogen fertiliser use in China. (Zhang W. , 2011)

Work carried out by Beijing University investigated the use of nitrogen fertiliser by farmers in a number of the main arable provinces in China. The investigation found over a third of all rice and wheat farmers were over-applying nitrogen, in some cases with application rates as high as 700kg N/ha (*Zhang F. , 2011*) despite overwhelming evidence that applications at these high rates was inhibiting yield. In a trial in Shandong Province researchers from China Agricultural University used an integrated approach to nutrient provision to reduce nitrogen use by 30% whilst achieving an increased yield by 16% (*Zhang F. , 2011).*

Province	Crop	Kg N/ha applied	Recommended rate Kg N/ha	% Overuse
Jiangsu	Rice	300	200	50
6 provinces*	Rice	195	133	47
North Chinese Plain	Wheat	325	128	150
North Chinese Plain	Maize	263	158	66
Shaanxi	Wheat	249	125	100
Shaanxi	Maize	249	125	>60
Shandong	Tomatoes	Up to 630	150-300	>80

* Guandong, Heilongjiang, Hubei, Jiangsu & Zhejiang

Figure 42: Typical overuse of nitrogen fertiliser in the main regions of China (Zhang W. , 2011)

CASE STUDY 14: NITROGEN FERTILISER ABUSE IN CHINA

The environmental problems created by the overuse of fertiliser in China are likely to be much greater than are already appreciated; little attention is yet given to the potential effects on ecosystems or even groundwater protection.

The reasons for fertiliser overuse are complex, though one of the most critical factors is likely to be the government's policy of providing subsidised fertiliser to farmers. Figure 43 below shows how for almost 50 years farmers in China have barely seen the cost of nitrogen change despite food indices increasing almost 20 fold over the same period. The current support provides reductions in electricity, tax and transport which in 2009 equated to RMB 700/t (£72/t). Urea currently costs farmers RMB 2,400 (£237.00/t).

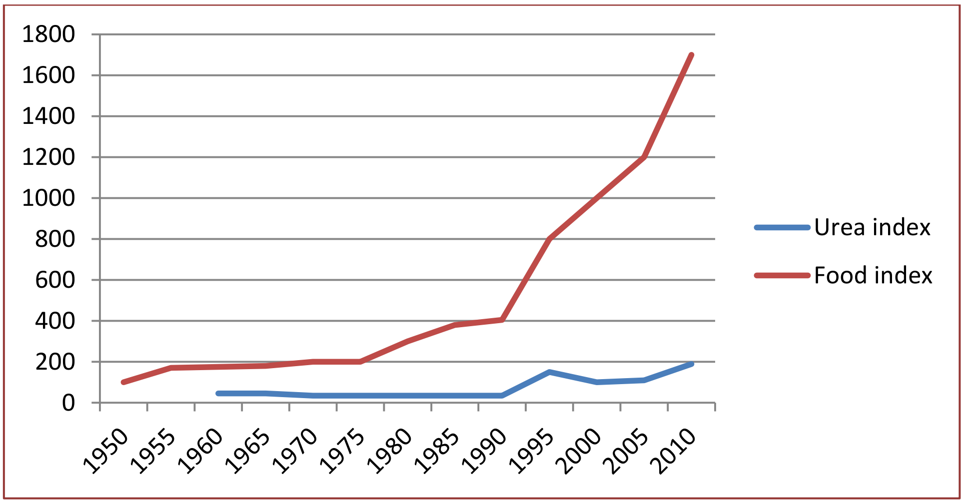

Figure 43: Changes in index of food and urea prices (1950=100) based on indicative data taken from data presented by Prof. Weifeng Zhang (Zhang W. , 2011).

Most farmers adopt fertiliser policies based on previous experience and there is a lack of technical knowledge. In a recent survey fewer than 30% of farmers in China knew what N, P & K were, and only 25% knew what a soil test was and only 4% had ever used one. The recent introduction of compound fertilisers has actually made the problem worse because of a lack of either soil analyses or understanding of the concept of compounds.

A frequent problem is not only over-application but incorrect timing and application method because most fertiliser is applied by hand. Recent investigations found that 70% is also applied within 40 days of drilling when plant utilisation is very low. In an attempt to improve timings and accuracy the government has encouraged the introduction of simple manual spreaders and these can improve application rates from 1 mu to 20 mu per day and farmers unable to afford them can make use of a trained application service.

The problem of fertiliser overuse has been recognized in China and the government has, in the last 5 years, allocated RMB 4.25 billion (£420 million) to a rapidly expanding programme to encourage more efficient use, though this has largely been motivated by international pressure to reduce greenhouse gas emissions rather than for agronomic or ecological protection.

7.1.4 ORGANIC NITROGEN

Livestock waste in the form of solid manures and liquid slurries are the main forms of organic nitrogen sources used by agriculture. A smaller proportion of organic nutrients from crop residues, and urban sources (sewage sludge, composted waste) and industrial wastes (food waste, paper sludge) also contribute nutrients.

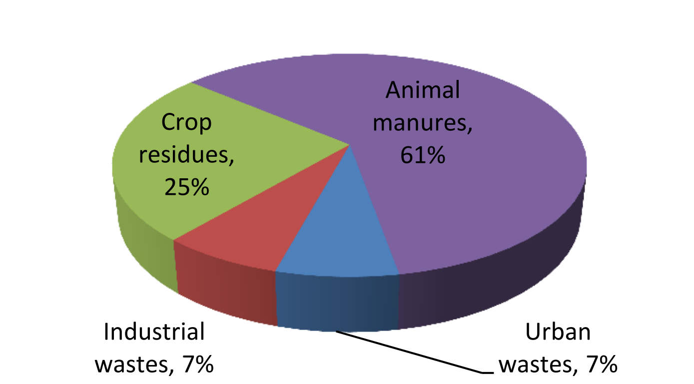

Figure 44: Organic wastes re-cycled for use on farm within the EU-15 (Association)

The use of manure derived Nitrogen across the EU varies from 15-225 kg/ha (figure 44). The amount of manure applied to specific crops in the EU is not well known and there are typically large variations by country and crop type.

Manures have the disadvantage of having relatively low nutrient contents. This effectively results in high transport and application costs relative to the quantity of nutrients applied. In many cases the application of organic wastes is motivated by the potential to improve soil organic matter content. Accurate application of organic materials can present challenges in achieving uniform spread patterns and accurate prediction of nutrient contents and availability. Typically farms will apply organic manures, make an assessment of likely nutrient supply and then apply inorganic nutrients to make up the balance.

Figure 45 below shows the relative variations across the EU of nitrogen supply from grazing deposition, manure application and inorganic fertiliser applications. Overall the UK has a relatively modest nitrogen application rate compared to other EU countries, and a particularly low level of nutrient contribution from livestock manures.

Manures and slurries estimated at in excess of 900 million tonnes across the EU-15 are spread on agricultural land each year, and 56% in the form of slurries. Livestock wastes contain an estimated 6.4 million tonnes of

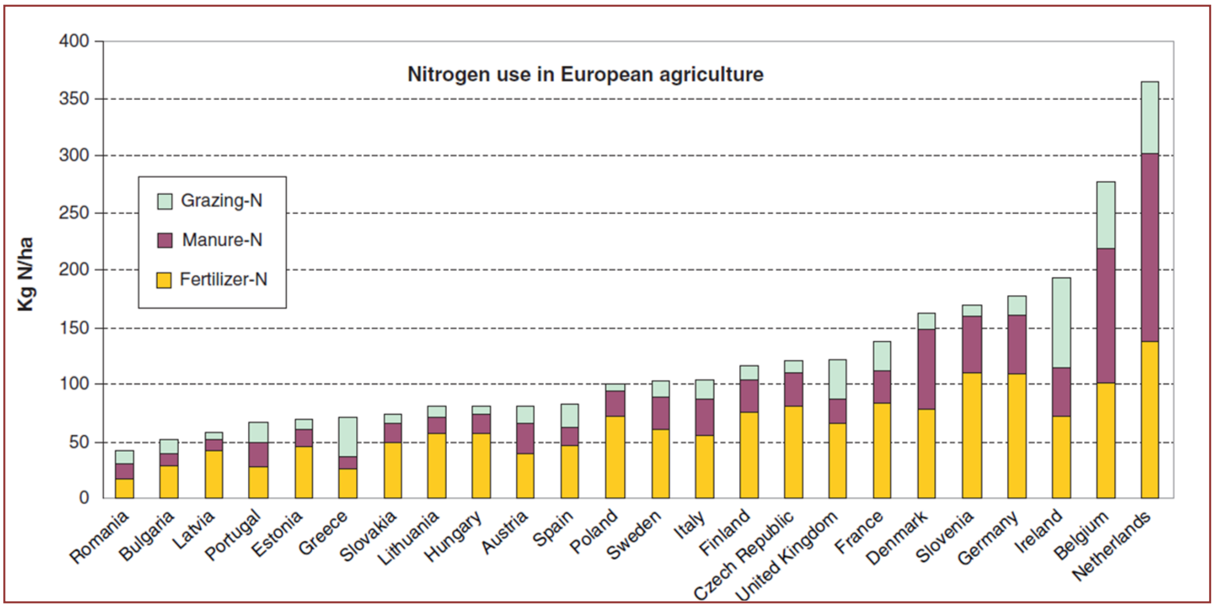

Figure 45: Average annual nitrogen inputs of fertiliser and manure (including applied and grazing deposition) to agricultural land in the EU (Jenson, 2011)

nitrogen. Livestock manures vary widely in nutrient levels according to the source species, housing systems and even from farm to farm depending on differences in management and particularly in feeding systems. Nitrogen is present in manures in two principal forms:

- Readily available nitrogen: - This is reactive nitrogen in the form of ammonium, nitrate and uric acid. Such forms are potentially available for rapid uptake by crops. Slurry and poultry manures are typically high in available nitrogen; nitrogen in this form is also readily leached and presents significant environmental risk if applied in inappropriate situations.
- Organic N:–In this situation the nitrogen is largely bound up as organic material and is only made available as the organic fraction mineralises slowly into ammonium and subsequently nitrate. Farm yard manure (FYM) is a high organic N material. The slow breakdown and release of the organic fraction means that only a small part of the nitrogen is available in the year of application.

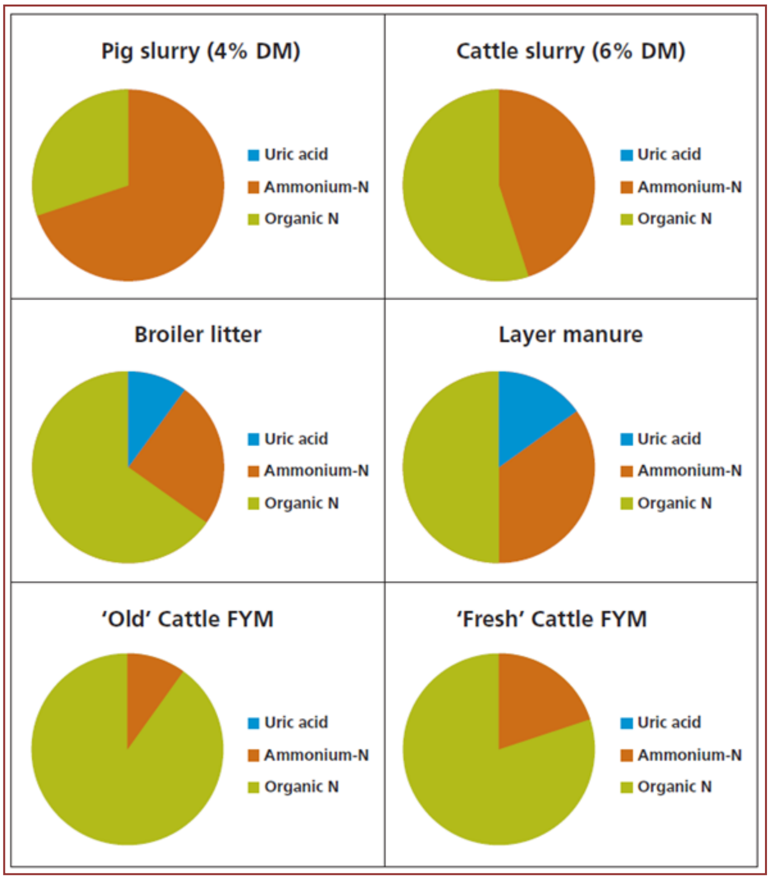

Figure 46: Typical proportions of different forms of nitrogen in livestock manures (Department for Environment, Food and Rural Affairs, 2010)

Figure 46 highlights the variation in relative availability of nitrogen in livestock manures. In the UK nitrogen fertiliser regulations typically discriminate according to nitrogen availability. Materials with high levels of available nitrogen such as poultry manure, pig slurry, cattle slurry and broiler manure are in some cases subject to application timing restrictions and additionally to rules which dictate application methods. The imposition of regulations such as IPPC and Nitrate Vulnerable Zones (NVZ) in the UK have in recent years improved the utilisation efficiency of organic fertilisers; this has resulted in the reduced use of inorganic nitrogen sources. In Denmark where similar regulation was imposed nitrogen fertiliser use has declined by 50% since 1990. In the same period a monitoring programme also showed that nitrate leaching reduced by 41% (Grant, 2009).

7.1.5 NITROGEN FERTILISER FORMS

The main forms in which nitrogen fertilisers are available in the UK are ammonium nitrate (33.5-34.5% N); ammonium sulphate (21% N, 60% SO3) and calcium ammonium nitrate or CAN (26-28% N): The nitrate-N in each of these products is immediately available for crop uptake. Whilst the ammonium-N can be taken up directly but is quickly converted to nitrate by soil microbes.

Urea (46% N) is also a widely available fertiliser though its use tends to be greater outside the UK. Before uptake by plants; urea-N must first be converted to ammonium-

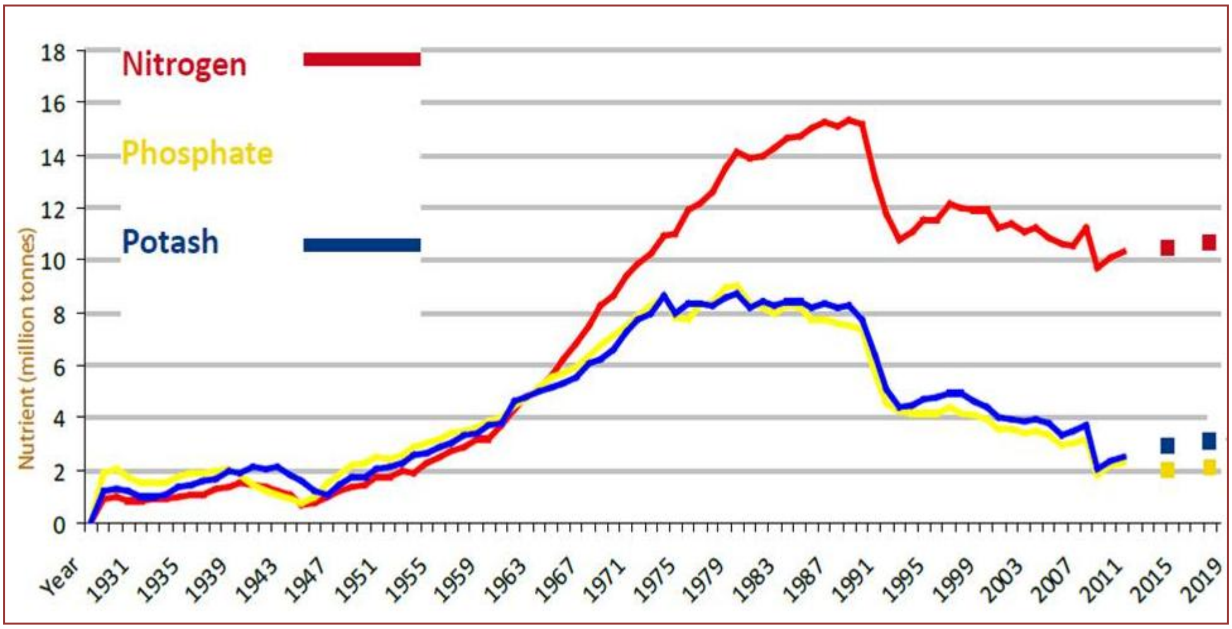

Figure 47: Total fertiliser consumption in the EU27 from 1927-2010

N by the enzyme urease that is present in all soils. This process usually occurs quickly and does not significantly delay the availability of the nitrogen for crop uptake. Typically, around 20% of the nitrogen content of applied urea may be lost to the atmosphere as ammonia. As a result less nitrogen is available for crop use and emissions may lead to impacts on biodiversity and human health. Losses are more closely related to the soil moisture and weather conditions than to soil type, and may be minimised if urea is applied shortly before rain is expected, and/or is shallowly cultivated. Urea is a low-density material which, in prilled form, can be less easy to spread accurately over wide bout widths when using spinning disc equipment.

Liquid nitrogen (18-30% N fertilisers are solutions of urea and ammonium nitrate. The nitrogen is in forms that are quickly available for crop uptake. Solutions based on urea alone will contain no more than 18% N because at low ambient temperatures urea crystallises out of solution.

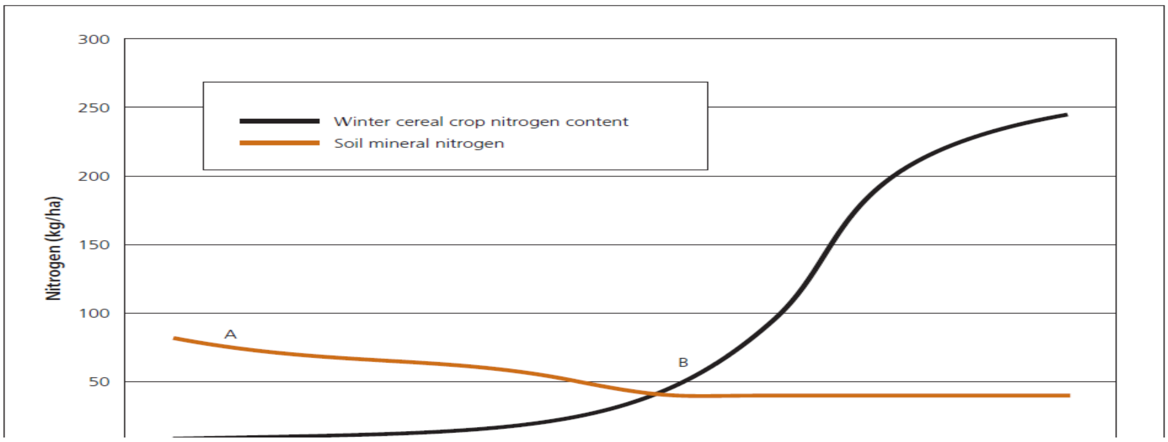

Figure 48: Nitrogen uptake by a winter wheat cereal crop in relation to available soil nitrogen (Department for Environment, Food and Rural Affairs, 2010)

7.1.6 PRINCIPLES OF CROP NITROGEN REQUIREMENT AND APPLICATION

Matching the nutrient requirements of a growing crop is critical if the crop is to make optimum use of inputs. Most soils contain relatively little natural nitrogen to meet crop needs, consequently supplementary applications of nitrogen are required.

The 'crop nitrogen requirement' is the amount of nitrogen that should be applied to give the optimum economic yield. DEFRA publishes comprehensive nitrogen application recommendations in the form of a fertiliser manual (Department for Environment, Food and Rural Affairs, 2010).

The application timings of nitrogen to a crop are important to ensure that crops make best use of the nitrogen applied at the start of periods of rapid crop growth and nitrogen uptake. Figure 48 shows how a typical autumn sown wheat crop takes up nitrogen:

- In autumn/winter (A) there is only a small nitrogen requirement that can be easily met by soil reserves. There is no requirement for additional nitrogen from manure or fertiliser.
- The main period for fertiliser uptake is March-June(B), and during this growth phase there is usually insufficient soil nitrogen to support unrestricted growth. Nitrogen fertiliser is applied at the start and during this phase.

Figure 49 shows the practical implications of supplying nitrogen at the correct timings. Typically, a crop grown on a site with limited residual soil nitrogen will require 240kg nitrogen per hectare. The nitrogen is normally split into 3 separate applications. The first application is usually limited to about 40kg - to minimise losses and is applied as the crop is actively tillering. The two subsequent applications are made during stem elongation at the higher rates of 100kg/ha since the risk of environmental losses is reduced in the later months.

Figure 49 also demonstrates clearly the difficulty of making significant use of organic nitrogen sources such as slurry. Prior to mid

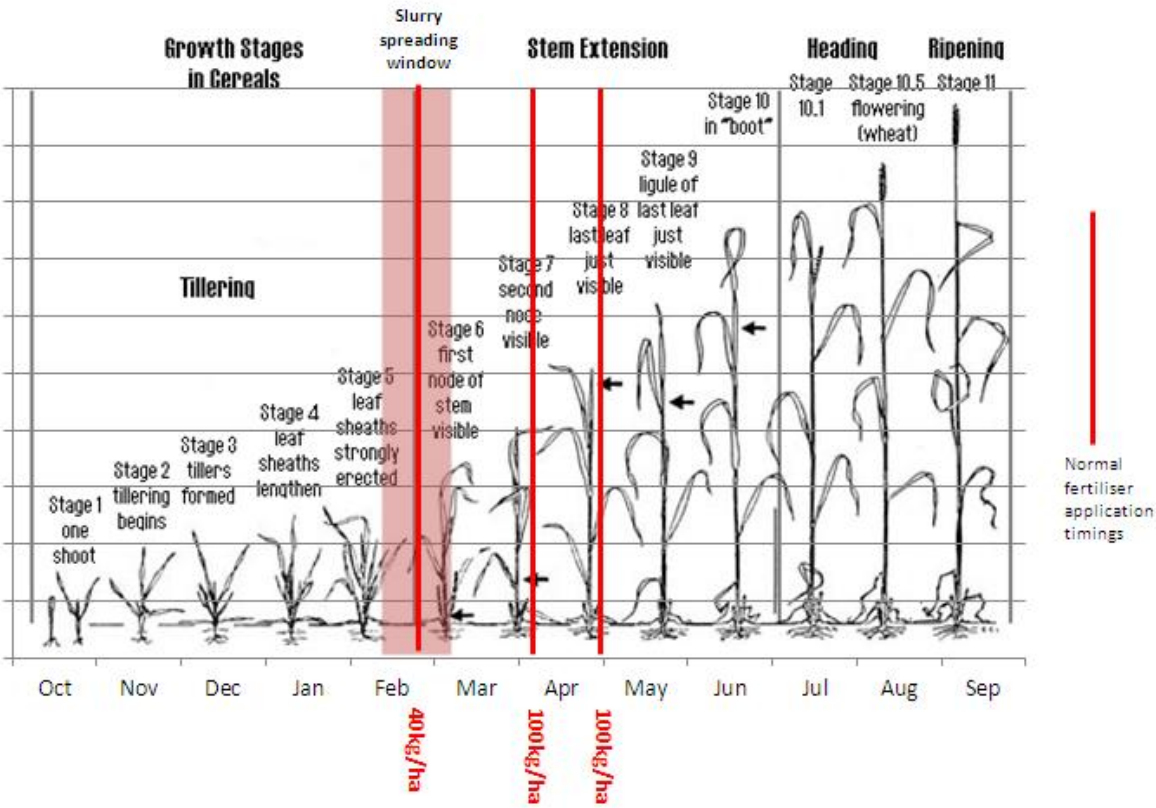

Figure 49: Typical wheat growth pattern, the normal split of nitrogen applications and the window for slurry application

February there is no requirement for additional nitrogen and any slurry applied is likely to risk entry into the environment. Ground conditions are also usually limiting at this time and with wet soils making the use of heavy slurry application equipment impractical. The other limiting factor is that once the crop has reached first node stage, typically in mid March, the use of machinery such as umbilical hoses will cause crop damage that is unrecoverable. The constraints created by the bulky nature of slurry and associated heavy machinery requirements limit the contribution that organic nitrogen forms can make to overall nutrient requirements.

7.1.7 NITROGEN LEAKAGE

The human production of reactive forms of nitrogen causes a cascade of intended and unintended consequences. The intention is that each kilogram of nitrogen contributes to soil fertility and increased yields of crops and animals to subsequently feed people. In a well managed system the intention is for the nitrogen in manures and sewage to all recycle back into the agricultural system (figure 50 blue arrows). The reactive forms of nitrogen are extremely mobile emissions, and losses can create an unwanted cascade of losses into the natural environment.

Figure 50 summarises the European nitrogen budget in its simplest form. The budget shows that overall the human effect is created by agriculture. Most reactive nitrogen flows into crop production and most of this production is used to support livestock rather than being fed directly to people and this equates to 80% of the nitrogen. These major alterations in reactive nitrogen cause many unintended nitrogen flows. Overall, in Europe, agriculture loses 3.2 Tg per year NH3 as well as 70% of nitrous oxide (N2O) emissions. The food chain further dominates nitrogen losses to ground and surface waters, mainly as nitrates (NO3) from agriculture (60%) and discharges from sewage and water treatment systems (40%).

The comparison between 1900 and 2000 shows how each of these flows have increased. The models demonstrate that there are huge opportunities to intercept the leakage of nitrogen into the environment through the adoption of effective technical solutions.

Throughout my travels I have searched for solutions to these problems. While looking at nutrients and particularly environmental protection I was beginning to see agriculture and the food system in terms of excess deficiency. In many parts of the world you see concentrated livestock operations creating environmental damage through excess nutrient generation. Elsewhere

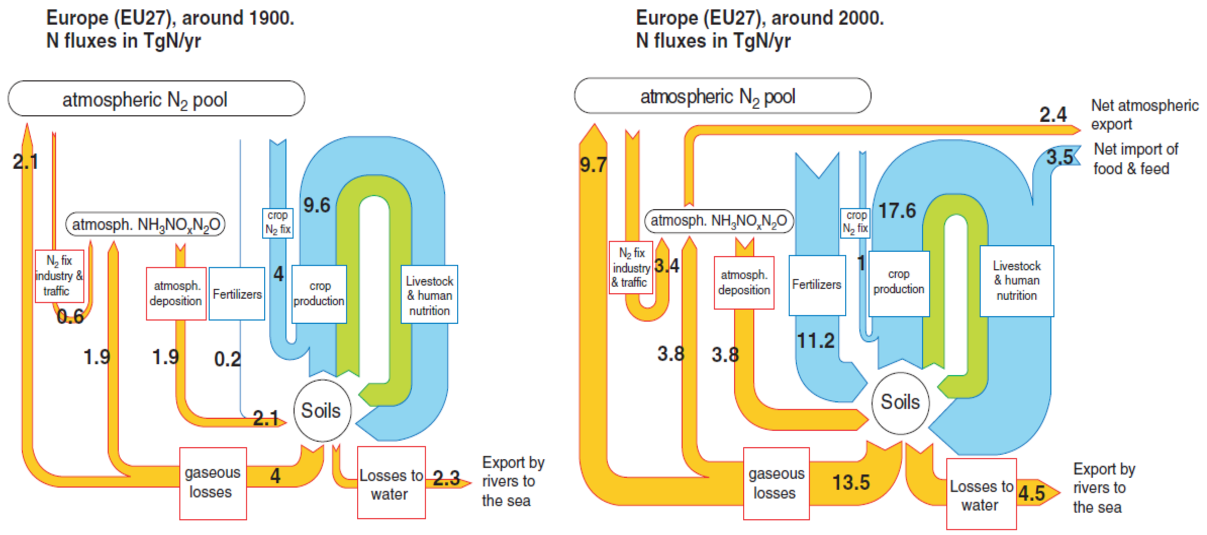

Figure 50: Simplified comparison of the European nitrogen cycle (EU27) between 1900 and 2000. Blue arrows show intended anthropogenic nitrogen flows, orange arrows show unintended nitrogen flows, and green arrows represent the nearly closed nitrogen cycle of natural terrestrial systems

intensive cropping was degrading soils of organics and exhausting nutrients. These nutrients are then being provided by the manufacture of additional artificial fertiliser. It seems logical that sustainability lies somewhere in the middle.

7.2 PHOSPHATE

Phosphorous underpins global agriculture and it is a fundamentally important element for the existence of all life which cannot be replaced by any other. This was recognized by Franklin Roosevelt who, in an address to Congress in 1938, said "I cannot over emphasise the importance of phosphorous not only in agriculture and soil conservation but also to the physical health of the nation. It is therefore high time for the nation to adopt a national policy for the protection and production of Phosphorous for the benefit of coming generations ………. ."

7.2.1 SUPPLY AND DEMAND

Most phosphorous is obtained from mined rock phosphate of which 90% will be used in food production. Currently this equates to 148 million tonnes per year (*Gunther, 2005*) which is principally used as a crop fertiliser.

According to Luc Maene of the International Fertiliser Association the annual global use of phosphate fertiliser as P2O5 represents 45 million tonnes. Demand for phosphate grew exponentially between 1948 and 1988 only to be checked by the collapse of the Soviet Union and, again, in 2008 by the global slowdown. In 2007-08 the same pressure that caused the huge increases in food prices led to phosphate rock and fertiliser prices to increase by 700% in a 14 month period (*Minemakers Limited, 2008*) The trend in demand is now starting to diverge according to the market. Developed regions such as Europe and North America have been reducing demand largely as a result of improved utilisation efficiency, regulation to protect the environment, and the increased use of organic forms of phosphorous which in Europe alone now account for 50% of the P source. In the rapidly developing countries such as China consumption is now starting to slow after a period of surging demand. The effect has been an equal surge in environmental pollution associated with its misuse. In addition there is limited knowledge in the region about the potential for recycling of organic forms which contribute only 30% of P. It is the undeveloped regions of the world that are now fuelling the growing demand for phosphate. The sudden spike in the price and demand for fertilisers in many of the developing countries during 2008 took many farmers by surprise. In India which is totally dependent on imported supplies of phosphate, the result was farmer riots, deaths and suicides due to the national shortage of fertilisers (*Bombay News, 2008).*

The IFA are currently developing modeling systems that will help determine how demand will develop through the current century. The number of potential variables makes this a significant challenge. Demand will be influenced by factors such as the development of technology to allow greater re-cycling of nutrients, population trends, food demand and the form that it takes, because meat consumption has a higher demand than crops.

Until the model is developed the IFA makes use of its existing outlook system which predicts that P demand will continue to grow by an average of 3.1% per year.

In an analysis of phosphate supply from 1995-2015 carried out by IFA (*Maene, 2011)* it was clear that China will become the most important phosphate manufacturer in the world. The other most significant region is North Africa including Morocco, Tunisia, Senegal and Algeria. There are also isolated deposits in South Africa. North America is declining progressively as a producer not through a lack of reserves but through high levels of regulation particularly around the Florida deposits. It can typically take 12 years to get sufficient permits in place to set up a mine. Supplies from South American producers are also increasing as a number of new mines come on stream in Peru. In Saudi Arabia there is very significant capacity also about to come to the market. Figures produced by the IFA suggest that there is sufficient capacity to satisfy demand will shortly be available. However, Luc cautions that in reality supplies through to 2015 are likely to be tight because of delays in projects to secure new sources.

Luc explains that to develop a phosphate mine is not an activity to take lightly. A typical mine will cost $3.5–4 billion and will show no return for 6-7 years. It was because of these huge capital requirements that most mines were developed using public money, but now that money is scarce there is heavy reliance on the private sector that will come forward, though until it does, supplies may be restricted.

There has been considerable debate over what level of phosphate reserves exist and controversy over the issue of peak phosphorous and whether or not this point has been reached? The main difficulty in determining reserves relates to the definition of what is economically recoverable. As technology improves and as demand increases and prices rise, reserves that were previously considered unviable start to come within economic reach of mine owners. Phosphorous itself is actually a renewable resource, which persists in the environment and in theory can be retrieved for re-use. However, phosphate, which is the fossil form, is considered to be non-renewable and has been the principal source of phosphorous over the last century.

Estimates of the extent of reserves have varied widely. According to a recent Soil Association publication *(Association S. , 2010)* which says phosphorous availability will peak by 2033. More recent reports from the US geological survey suggest that this is overly pessimistic and the reports also highlight how previous estimates have not taken into account some of the largest projects including the Saudi one now coming on stream. The USGS estimates slightly exceed the International Fertiliser Development Centre's whose figures put reserves at 60 billion tonnes of rock and resource at 290 billion tonnes. 'Reserves' relate to rock phosphate which is currently accessible through existing technology and prevailing economics, whilst 'resource' refers to rock phosphate that is known to exist but is not yet either technically or economically viable. These resources have every chance of becoming reserves if history is any indicator. Until recently China was unable to deal with rock with less than 30% phosphate but today it is working to levels as low as 20%.

Phosphate is an international commodity like any other, whose future is dictated by supply and demand. High levels of demand in recent years have seen prices climb and investment take place to increase supply. Since 2008 the fertiliser industry has invested $40 billion in phosphate. It is anticipated that a further $40 billion will have been invested between 2010 and 2015.

7.2.2 PHOSPHOROUS UTILISATION

Irrespective of the level of reserves no-one disagrees that phosphorus is a finite resource and that it requires careful stewardship. It therefore seems almost perverse that we abuse its use. The way in which we abuse its usage seems therefore almost perverse. In the case of a typical UK dairy situation, phosphorous inputs usually exceed the outputs. Phil Haygarth from Lancaster University suggests that P accumulation is common in much of the world's developed or developing agriculture. Using his typical UK dairy farm example he suggests that 60kg of P per hectare is typically added to the system both as fertiliser and feed supplements, but of this only 30kg is usually removed as product and the remainder accumulates in the system.

Across the EU it is calculated that 12 kg/ha excess P is applied annually and the result is a steady increase in the Olsen P (agronomic measure of phosphorous levels) status of soils. Since P is not particularly mobile this build up tends to be largely in the soil upper layers. Essentially, we are exhausting natural reserves of phosphorous but building up excesses in soils. It is the link to water which is the main problem associated with excess phosphorous. Whilst it has no gaseous phase it is relatively stable compared with nitrogen but does enter an aqueous phase where soil particles containing phosphorous travel to watercourses through erosion, or via the runoff of nutrient laden manures through inappropriate application. The natural ecosystem can be incredibly sensitive to the movement of P. One of the most dramatic effects is that of eutrophication, the buildup of toxic algae and phosphate in the ecosystem.

There is significant opportunity to reduce the demand for artificial phosphate. By ensuring that applications are both appropriate and accurate utilisation efficiency can be as high as 90% thereby significantly reducing environmental losses. Technology can also contribute and there is a lot of interest in understanding how better use can be made of organic P. Phosphate exists as both mono and di-ester organic forms. If ways could be found to make these forms more available it has been suggested that sufficient additional P could be released to support a typical intensive grass or arable system for 70 years, or a more extensive system for 5,000 years.

Other work is focused on biotech solutions to improve root architecture to make plants more successful at removing P; and by examining increasing absorption of P by manipulating plant enzymes to increase organic acid excretion. The use of modified soil microbes also offers promise to increase the turnover of P.

Perhaps one of the most urgent and game changing solutions to the problem of excess nutrients in the environment is the work to interrupt the P flux. Like livestock, people eat and excrete huge amounts of P but, unlike livestock, much of the P from this source leaks into the environment. There is currently a lot of work taking place to develop systems to recapture and reuse P from waste streams and reuse. This is particularly the case in the regions where P-based ecological damage has

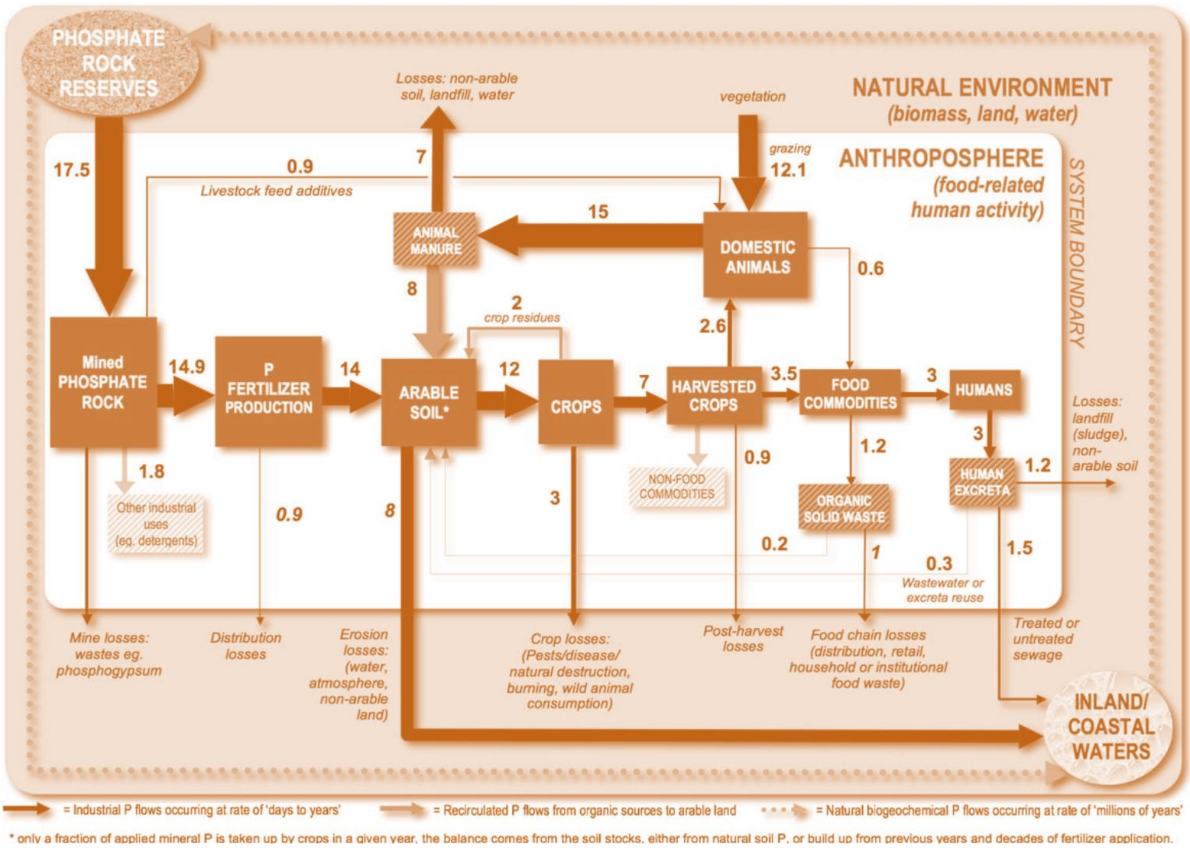

Figure 51: Phosphorous flows through the food cycle (Dana Cordell, 2009)

been particularly high such as the USA, Canada and Europe. Case study 14 describes one such technical solution being developed by a Canadian based company

A systematic approach to the analysis of phosphorous flows through the food production cycle can reveal where losses and inefficiencies occur. An attempt to quantify and describe this flow is detailed in figure 51 (*Dana Cordell, 2009).* In the diagram the inner white area is known as the 'Anthroposphere', which defines the human activity system that in this case is largely related to food production. The outer area is the 'Natural Environment' and includes the biogeochemical processes through which phosphorous is released by processes such as weathering, typically at rates which can be measured in millions of years.

Currently, approximately 17.5 MT of rock phosphate is mined to be processed into 15 MT of phosphorous fertiliser. The fertiliser is augmented by phosphorous from organic sources such as animal manure (approx 8 MT) and crop residues (2MT). It is estimated that the global harvest removes just 12 MT of the annual input of 25 MT P into the soil. Studies of post harvest losses have suggested that approximately 55% of phosphorous in food is lost between 'farm and fork'. Globally it is estimated that 50% of the phosphorous consumed and hence excreted by livestock is returned to agriculture (*Smil, 2000).* Close to 100% of the phosphorous eaten by people is excreted in urine and faeces which equates to 3 MT P globally. Since over 50% of the world's population now lives in cities, they are becoming nutrient concentration sites. The model demonstrates that only a small fraction of the phosphorous in the system is actually offsetting and reducing the amount of rock phosphate required each year, and virtually the amount recycled back to agriculture is equal to that lost directly through erosion alone

The implications are clear in that we are currently mining five times the amount of phosphate that is actually consumed by humans in food; there are significant losses throughout the system which should be looked on as resources to utilise.

CASE STUDY 15: PHOSPHOROUS RECOVERY, ALBERTA, CANADA

A small company based in Canada with a pedigree in the treatment of contaminants in soil has been developing a solution to deal with one of North America's biggest environmental problems: the eutrophication of water courses as a result of phosphate pollution. All too often the source of the pollution is agriculture, particularly the intensive livestock sector.

The company has developed a treatment system to take manure in slurry form and put it through a series of processes to progressively reduce it in volume and partition some of the key nutrients.

The process starts with the removal of all solid particles which can then be spread to land or further processed using drying or pelleting. The liquid element is further treated to produce one fraction in which the dissolved nutrients are concentrated and a second fraction which is clean water that can be used as process water or simply discharged.

Fig 52: the developers of the de-watering system at one of their first installations in Alberta, Canada.

By reducing the volume of the slurry the following is achieved.

- It is possible to deliver desired nitrogen levels with much smaller application volumes; this removes the need to apply more than one application and increases the window of opportunity to apply material.
- The dewatered material has all suspended solids removed which results in a clear liquid. The options to apply this material are significantly increased compared with raw slurries. More sophisticated application systems such as liquid fertiliser spreaders can be utilised.
- The ability to utilise liquid fertiliser application systems increases the window of application, crop damage is prevented through the use of tramline compatible equipment and the risk of crop contamination is avoided by the removal of all suspended solids.
- The concentration of nutrients in the dewatered slurry improves the efficiency by which the material can be transported; land that was previously considered beyond economic transport distance for conventional slurry is potentially suitable for separated slurry.
- The storage requirement for slurry can be significantly reduced as a result of de-watering.

8.0 THE NECESSITY OF KNOWLEDGE

Summary:

There is a big difference between actual yield and yield potential. To close the gap will require a focus on applied research and the adoption of new scientific and technological advances. The integrated nature of the elements that create a sustainable system demands cross disciplinary approaches. Sustainability also deals with long term effects which require a different approach from the typical short term nature of modern research. There has been a shift in focus away from applied research to basic research, and this has been accompanied by a dismantling of applied research and demonstration facilities and their associated extension capabilities.

8.1 A CALL TO ARMS

Agriculture's fortunes have always depended on high levels of technical knowledge and continuous advancement in our understanding of the mechanisms behind the biological processes we depend upon. Allied to this has been the need to develop technologies that can be deployed to take advantage of the knowledge base which frequently requires input from virtually all of the main sciences. Throughout my travels the critical contribution of science and technology has been driven home to me time and time again. But, equally, I also found myself questioning just how fit for purpose the knowledge-based community is to deal with many of the issues that a drive for sustainability will create.

Securing a sustainable world food supply will probably be one of the most pressing and laudable challenges of the coming decades. It will require urgent, cross disciplinary and international effort. The private sector alone will not deliver the necessary intervention so a strong publicly driven steer will also be needed. In the UK we still have capacity to contribute to the challenge.

8.1.1 STATE OF THE NATION

The shape of agricultural research across the world has evolved over time; it is an industry like any other, driven by the economic realities of supply and demand, and probably more so than other sectors since it has always been highly dependent on competitive public funding.

The evolution of the sector has seen a change in the nature of agricultural research. In many countries it used to be more applied and was closely tied to a network of extension workers or consultants who were not only charged with disseminating the results of research to the end users but would also feed back into the research community the most immediate problems faced by the industry. But in many countries, as in the UK, that system has largely been dismantled or cut back. The result has been an academic community that is increasingly disconnected from the industry to which it owes its existence.

Academia has developed a research focused culture that measures success by the number of papers published rather than the delivery of focused, economically and technically viable solutions to the real problems the industry faces.

The problem begins at an early stage in the career of a researcher. His success depends on reputation, and that reputation is earned by the number of times his name appears on publications. The focus then becomes the generation of papers where he features as an author. As you develop an expertise in a particular area you increasingly focus more narrowly on the subject surrounding yourself in a very specific cocoon of capability. Rarely would you consider involvement in a more applied multi-disciplinary project because your contribution would be watered down by many other names on the paper. This invariably results in a scientific elitism that rejects integration of disciplines; and this huge loss of opportunity is inexcusable.

During the course of my travels I visited over 15 universities and in every case the pattern was the same. I would make contact with one or two key individuals in the institution. I would explain how I was studying the sustainability of agriculture and searching for solutions to some very complicated problems that would face the industry in the future. Invariably they were incredibly helpful, furnishing me with a series of names, introductions and meetings. But as I visited each institution in turn a pattern began to emerge. If my initial contact was a soil scientist he would introduce me to every other soil scientist in the faculty; if my contact was an economist he would take me to every other economist he could think of. Only rarely did it cross their minds to take me to the floor above, or below, to meet other disciplines, even though they were clearly relevant to my study. It is this silo mentality that makes modern academia poorly structured to deal with many of the challenges of sustainability.

This is clearly not a model that fits well with the challenges that agriculture is going to face. This report has barely been able to touch on the future needs of world agriculture but the imperatives are still clear; we need increased production from a diminishing resource base while addressing the environmental impact of modern agriculture. The term 'sustainable intensification' has been coined to describe this. Faced with this challenge it seems clear that the existing research model is not fit for purpose.

By their nature sustainability issues are complicated; involving myriads of interactions and disciplines, and academia needs to acknowledge this. We need dynamic research groups that bring together a multitude of disciplines and knowledge, from the most fundamental blue sky researcher through to the land manager on the farm who has to implement change. Reputations need to be built not as individuals but through being a part of successful groups that deliver real outcomes to implement sustainable intensification.

We need a system that also recognises institutions that can deliver outcomes that have real impact. The current funding system for universities in the UK is partly based on assessing the quality of research in a process called the Research Excellence Framework. This process measures the quality of the institution's research output, as determined largely by other scientists. The result is the promulgation of scientific elitism where the most successful universities and research groups are rewarded by their ability to impress their peers in the research community rather than how well they contribute to dealing with real and immediate practical problems.

Within the university sector profile is everything because it brings funding and students. But that profile is often built around being good at fundamental science rather than applied science. There are many universities that are strong in the delivery of applied science, and that are close to the industry they represent and I count my own, Harper Adams University College, among them. But all too often a focus on applied research is actually seen as a weakness that relegates the institution to a perceived lower league than those involved in more fundamental science. The current assessment model penalises institutions like Harper Adams which have retained their close industry links and which, by remaining focused on applied research are deprived of core research funding from the Higher Education Funding Council (HEFCE). The loss was until recently partly offset by the HEFCE introducing the Higher Education Innovation Fund (HEIF). The fund is aimed at supporting knowledge transfer (KT) between universities and industry but does not replace the innovation created by applied research. In 2008/09 the fund totalled £112m across all subjects, though agriculture received a very small percentage and does not currently receive any of this funding. The fund is aimed at supporting knowledge transfer (KT) between universities and industry but does not replace the innovation created by applied research.

CASE STUDY 16: JIM HALFORD, ZERO TILLAGE PIONEER, SASKATCHEWAN, CANADA

Jim Halford did not set out to revolutionise crop production in North America, he just wanted to solve a problem on his farm. Jim was concerned about the amount of wind and water erosion, declining soil fertility and increasing soil salinity taking place on his farm at Indian Head in Saskatchewan. He had a theory that the intensive tillage systems commonly in use across North America were the problem. Jim had realised that where land on his farm had not been cultivated and was supporting native plants soil quality was still high. He wanted to replicate this by sowing direct into the surface without disturbing the soil or removing the plant residue on the surface. The fact that suitable equipment for his purpose did not exist was no barrier to Jim and he set about designing, testing and building until he had a machine suitable for the job. So successful was the system that he set up a company called 'Conservapak' to build and market the equipment. The company was subsequently acquired by John Deere and forms the basis of the latter's zero tillage range.

Jim has always been eager to share his experience and vision; his enthusiasm spurred many academics to take a closer look at what he was doing. He now has a range of sites across his farm that have been variously zero tilled for 12, 20 and 30 years, together with examples of conventionally cultivated areas. This has proved to be a fantastic resource for researchers from the University of Saskatchewan and Agriculture and Agri-Food Canada which in 1993 established the Indian Head Research Farm close to Jim's. Not surprisingly Jim was very instrumental in this.

Initially there was suspicion over the use of no-till. In the early days its adoption was associated with yield reductions. However for those farmers who persisted it became clear this was a transitional phase after which yields would usually exceed conventional systems. Today it is well understood that there is a need for additional nitrogen to be provided in those early years to replace nitrogen being immobilized in the soil as a result of the build-up of organic matter.

Figure 53: Jim Halford and production system scientist Guy Langford inspect a zero till system set up for research plots at the Agriculture and Agri-Food Canada research station at Indian Head, Saskatchewan.

Research can also be incredibly short term in its nature; a typical project revolves around a three year cycle which is typically the time it takes to carry out a PhD. This was not always the case. We have many examples around the world of long-term experiments such as the Broadbalk plots at Rothamsted or the Palace Leas plots at Cockle Park (Newcastle University). Researchers in the 19^{th} century recognised the value of long term research and today the results generated by sites like these are cited regularly around the world. Today's funding models for research do not lend themselves to this kind of approach.

In Canada I saw a stark example of the huge opportunities that can be lost through this short term approach. Probably the most monumental discovery on the North American plains in the last century has been the adoption of zero tillage (see case study 16). It resulted in huge amounts of land that would normally be left fallow being brought into production; it has significantly reduced soil damage and erosion and has improved the economic viability of farms. And yet when the system was assessed using a traditional three year research programme, the results suggested that it was not viable because the initial years of its adoption typically showed yield reductions. The only reason the system was so widely adopted was that a few dogged farmers persisted with it and did their own research, developing systems and technology to complement it. In many cases, once they were through the first couple of establishment years, those farmers were seeing huge improvements in the quality of their land and crops and suddenly researchers started to get interested in what they were doing.

Innovations related to improving the sustainability of agriculture require phases of invention, development, selection and finally implementation. The initial innovation needs an understanding of the long term mechanisms of agricultural systems. Solutions to the many sustainability issues such as climate change, soils, nutrients, water, energy, environmental protection as well as social and economic aspects can only fully be appreciated through long term projects that integrate these factors. Practical results need a long term view to establish the robustness of systems across the range of variables that exist in the real world and also to understand the knock on effect in what can be a very closely woven system.

An overhaul of the way science is carried out in the university sector is desperately needed if we are to address many of the issues of sustainability. Researchers need to reconnect with the applied end of the industry and better justification of the way in which research will be brought to market needs to be implemented. Those organisations charged with administering funding, assessing research quality and the appointment of research staff should have stronger representation from key stakeholders who understand the potential application of discoveries.

8.1.2 RESEARCH FUNDING

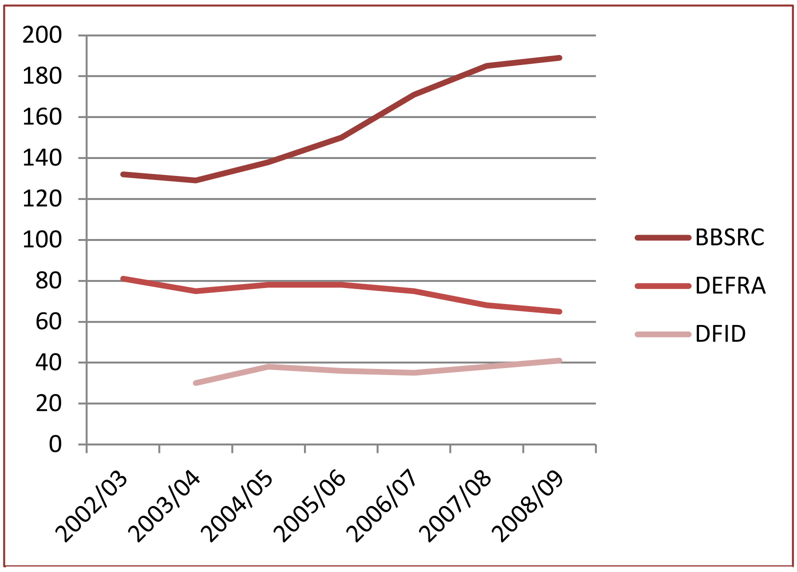

Figure 54: R & D funding on farming and food per financial year (Hansard, 2010)

The research community spends an inordinate amount of time pursuing funding; funding is rarely for more than three years at a time and the whole process of securing funding can take several months. This often means that researchers are locked into a cycle of starting projects and almost immediately starting to think about where the next tranche of funding will come from. It is a system that can see research departments lurching from famine to feast and does little to engender the confidence to make long term decisions to invest in staff or resources.

In recent history this pressure has been increased significantly by a considerable contraction in agricultural research funding and facilities. The phenomenon has been a global one but has been especially severe in the UK where we have seen the loss of both research and teaching capacity including many of the facilities responsible for work of international quality and relevance. Once lost such capability is not easy to restore. Many great institutions have been consigned to the history books, including Bridgets (dairy research) Cranfield (agricultural engineering) and quite recently The Horticultural Research Institute in Warwick to name but a few.

It is often suggested that the reduction in public sector support for agricultural R & D since the mid-1980s may also have contributed to the decline in growth of agricultural productivity (*Thirtle C, 2004).* This may partly explain the 1% per year decline in UK self sufficiency in food production.

Earlier this year a Commons question was tabled by the then Shadow DEFRA, Minister Jim Paice, asking how much had been spent on agricultural R & D in the UK over the last 10 years (*Hansard, 2010).* The answer revealed the significant shift from funding for applied and strategic research traditionally funded by DEFRA towards more fundamental research financed by the Biotechnology and Biological Sciences Research Council (BBSRC) as shown in figure 54. Policy since the mid 1980s has been based on the notion that concentrating research funding in high quality basic science will ultimately lead to the uptake of new ideas and technology by the industry. This model is based on the premise that market forces will take the innovations created by researchers and develop them through to final products.

This linear model largely leaves academia to determine the course of research and assumes that industry will automatically pick up the results of the research and take it to the next level. It relies on industry to keep scientific research results under review and exploit them when opportunities arise. This is an approach that can work well for certain products such as pharmaceuticals, pesticides and possibly crop varieties but for most of the world class basic science being carried out the effect on agricultural innovation has been minimal. Time and time again I came across researchers who would talk about how many technical solutions were sitting on shelves in laboratories around the world with neither the applied research funding nor the commercial interest to take them to the next stage.

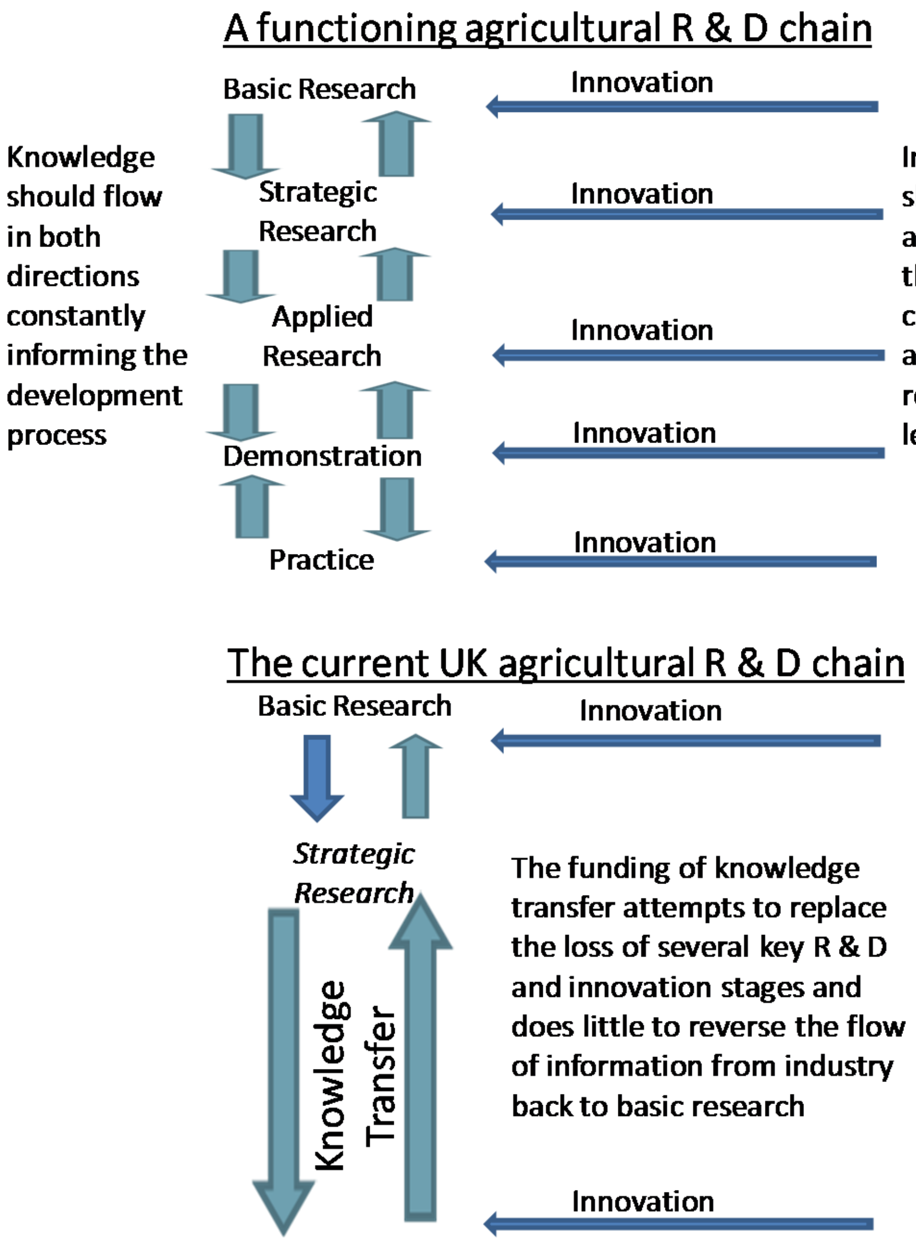

Figure 55: The ideal design of a fully functioning R & D model (above) and the current UK model (below) modified from, (The Commercial Farmers Group, 2009)

A successful research chain is not linear but is a two directional process. Knowledge should flow in both directions between scientists and the end user. In addition there remains a second stage between basic science and its end use that still needs innovation funding. This applied research should be seen as a key stage of the research chain and is also critical for the two-way flow of ideas between industry and research. Reliance on market forces has not created this joined up approach. The impact of this strategy has been the erosion of research infrastructure and expertise in universities and research institutions. There is now a vacuum between basic research and practice, which reduces the ability of new science to be translated into practice. The commercial farmers' group (The Commercial Farmers Group, 2009), a coalition of academics and producers who seek to promote debate on food security and agricultural competiveness in the UK. has suggested how a fully functioning R & D chain should operate (figure 55).

This erosion of applied agricultural capability is removing career opportunities for young scientists which, coupled with the loss of a generation of researchers who understood the translation of science into practice is simply increasing the vacuum of capability in the UK. All too often 'knowledge transfer' is promoted as the way to translate basic research into practice, but this does not however replace innovation or practice developed by applied scientists.

It should also be borne in mind that agriculture's structure is one of micro-businesses which can be inherently low in profitability. However farmers in the UK make a direct contribution to research through the payment of levies to the various bodies of the Agriculture and Horticultural Development Board (AHDB). The value of the funding is relatively small, amounting to about 0.3% of UK agriculture GDP, but where investment is made in agricultural research the return can be significant. Research suggests that while returns are variable (10-50%) the average rate of return is about 15%.

CASE STUDY 17: THE REAL IPM COMPANY, THIKA, KENYA

The real IPM company is passionate about bugs, specifically the use of natural predators and other biological controls, to protect crops from pests and diseases. The company was formed by husband and wife team Henry Wainwright and Louise Labuschagne in 2004. It has grown rapidly and now has a network of 10 regional field consultants and over 100 staff and sells products into not only many African countries but also Europe and Canada.

Integrated Pest management (IPM) is defined by the company in simple terms, as being about using means to protect crops from pests without over reliance on pesticides. The company offers a range of biological means particularly aimed at the cut flower industry where cosmetic damage to flowers can seriously affect the value of a crop. Kenyan growers have very much been at the forefront of adopting IPM in flower crops

Figure 56: Left, Mature Phytoseiliulus persimilis are harvested in greenhouses where they are produced in controlled condition. Right, A mite also has to be produced separately to provide food for the production of the Phytoseiliulus persimilis.

The company's main products are soil inoculant Trichoderma, the growth of which is associated with the reduced infection of other microbes,and a mite Phytoseiliulus persimilis. The mite predates on the red spider mite, which is probably the most damaging pest in the Rose and Dianthus industry. In a conventional protection program over 50% of the cost can be associated with spider mite. Phytoseliulus has a significant advantage over pesticide sprays in that it is able to seek and destroy, unlike sprays which rarely cover the plant completely.

The use of biological controls requires high levels of technical ability to ensure that the mites are deployed at the correct time and in the correct ratios of predator to pest. An understanding of the population dynamics and relationship between the pest and predator are critical and as such the company often provide growers with comprehensive training programmes or contract scouting services.

The production of Phytoseliulus is equally technical. Prey species need to be produced in separate facilities. They are introduced onto a suitable host crop which is typically a bean and this is followed by the predator whose numbers build naturally until they are harvested for packaging and dispatch to growers.

8.1.3 TECHNICAL DEVELOPMENTS

The UK's largest staple crop is wheat and yet yield growth of this important crop has plateaued for many years now. Compare this with soya and especially corn where yields continue to increase year on year. The big difference is nothing intrinsically to do with the crop but according to the Director of Rothamsted Research, Professor Maurice Moloney *(Moloney, 2011*) and many other plant scientists, it is the result of a lack of investment into the development of the crop. As a result it has, as Moloney puts it, been 'under technologised'. Corn got its first big boost between the great wars when the first hybrids were developed. For many years the yield curve grew substantially but it was beginning to flatten in the 1970s in exactly the same way as wheat today - then came biotechnology methods and genetic manipulation. This corrected the curve and we now have a situation where yields of 14-15 t/ha are a reality. This growth does not seem to be abating but has come at the cost of an awful lot of investment. Some suggest that the disparity between wheat and corn is related to the use of GM technologies. This is part of the story but not all. The role of GM in the maize story has been confined to pest protection, weed control through the use of 'Roundup ready' varieties and resistance to damage by the corn borer. Equally as important has been the use of gene marker assisted breeding technology. We are at a stage where most of the corn genes and their traits are now known so we can follow quantitative gene loci in a very specific way, building them up in hybrids and in doing so maintaining the growth in yield. Corn has been a wonderful story because it has become a very modernised crop in terms of the techniques applied to it. Monsanto, for example, now has access to a 'Corn Chipper', a fully automated complete genotyping machine, which can work on individual seeds without destroying them. This allows researchers to identify a seed that contains the positive trait they require and then grow it on in a breeding programme. Because corn has had the benefits of system biology, molecular biology and automation applied to it so completely, unlike wheat, it just keeps on giving.

The obvious question is why has this not happened in wheat? The simple answer is that there has not been the profit motive because wheat has always been a self pollinated crop with no hybrids and so people keep seed as opposed to buying it each year. As a consequence there is not the same level of commerce driving development. This is a classic example of the need for public funding where reliance on the commercial imperative alone cannot deliver.

Back in the 1960s there was a similar dilemma. The yields of staple crops like wheat and rice across the world were insufficient to prevent widespread malnutrition. Norman Borlaug famously drove the solution which would come to be known as the green revolution. Borlaug concentrated on regions where crops yields were significantly below potential, such as in parts of Africa and India where yields were typically 1/5th of those in the UK. Borlaug set about improving agronomy practice and matching genotypes to the environment, famously introducing the dwarfism characteristic into cereals to improve harvest indexes and reduce the risk of lodging. The commercial imperative did not exist in the 1960s, as in the case of wheat today; the work of Norman Borlaug was publicly funded by the Mexican Government, and the Ford and Rockefeller Foundations. Today, the world still faces the same challenge. Staple crops such as wheat need to have their potential improved but there is also significant difference between yield and potential. In Africa wheat yields are typically 1.5 t/ha against a world average of 2.5 t/ha and a UK average of 8.5 t/ha.

The green revolution was a paradigm shifting event but its momentum was not maintained. Today we still see images of aid being handed out to the starving coming out of regions like Kenya, Somalia, and Ethiopia. And while that is absolutely the right thing to be doing one has to ask why such regions still do not have access to the most basic technology and knowledge to realise the potential available to agriculture in the region. There is clearly a lack of investment in the old cliché 'give a man food and he will feed his family for a day, show him how to produce that food and he will feed them forever'.

The agribusiness companies have not touched wheat for many years because their focus has been on soya, corn and cotton which are big acreage crops largely grown in countries that have accepted genetic modification. The backlash in the EU against GM has been linked to the companies that have backed off clearly not prepared to make investments in crops that may be prevented from having a market.

We are now almost moving into technology beyond GMOs. We are sequencing entire genomes, and now have methods of carrying out *in vivo mutagenesis* which means that we can site-direct a mutation and leave no other effect on the plant except the mutation. So if, for example, we knew herbicide resistance in wheat could be a positive trait we could go into the plant and modify target sequences like EPSB Synthase to create a herbicide resistant plant. The technology is not yet entirely commercial but it exists and most of the relevant companies have access to it.

The obvious risk is that even these alternative technologies could get caught up in the same anti-technology backlash that affected GMOs. We should not underestimate this risk because we have not yet come up with satisfactory ways to communicate with the public to allay their suspicions or provide a robust case for technology intervention. If anti rationalism is not addressed and the rest of the world continues to move on adopting technology, will we end up building a wall around Europe by saying we will not allow in food produced by these technologies? For a region that is so far away from self sufficiency that seems unlikely, so instead we could end up with a form of hubris, importing the food produced by systems declared illegal in the EU. The rational basis of any legislation would then fall apart.

Whose fault is this? During the first round of the GMO debacle in Europe; academia headed for the trenches and failed to embrace the debate. Instead they continued to develop genomics for 10 years and at the end of that period they had lots of ideas about the fantastic things they could do with genomics even though they were not allowed to employ these techniques in Europe. When you look at all the big economies like the USA, Brazil, China, India, Canada and Argentina who are all embracing the technology as part of their food security solution, you have to ask: is Europe really going to be left so far behind? And when you look at the parts of the world using pesticides, Europe is now the heaviest user since countries employing GMOs have been able to reduce their use so significantly. It should be an environmentalist's dream.

The sort of story that should be able to resonate with people is the reduction in the amount of insecticide used in the US since the introduction of GM corn and cotton. These have saved over 46 million pounds of pesticide (*Sankula, 2004*). For many years there it has been hoped to put biological controls into the field to reduce the effects of pesticide and while bio-controls such as those developed by the Real IPM company (case study 17) are applauded no credit has been awarded to the potential of GM even though its benefits are real.

Whole genome sequencing gives us a much better understanding about how organisms function biochemically, which opens the way for much more ambitious ideas such as nitrogen fixing cereals. Back in the 1970s research teams worked extensively on this topic but just did not have the technology to get there

Another related nitrogen idea comes from sugar cane, an incredibly productive plant that seems to survive on negligible nitrogen inputs. Recent discoveries may have found the reason behind this. Many varieties of sugar cane seem to have, throughout their leaf systems, nitrogen fixing bacteria which mean that to some degree they are acting as legumes. If we could get these free living bacteria to function as symbiomes in cereals for instance, it would make an enormous difference. Not only would you get biological nitrogen fixation very efficiently but you would also reduce substantially losses of fertiliser nitrogen through leaching and also the greenhouse gas impact of cropping associated with artificial nitrogen fertiliser production. These kinds of technology are long term and critically require a public funding approach. A key strategy has to be to replace the Haber Bosch process with a biological alternative.

Other potential opportunities are closer to market and that then becomes a problem. An example of this is algae which are featured in case study 18. One species Spirulina has been on the planet over 3.6 billion years which has allowed it to evolve into a remarkable plant capable of producing huge amounts of high value biomass while potentially utilising waste nutrient sources and poor quality land.

There needs to be national and international strategy at the heart of whatever we are doing and it will need to be routinely re-visited because the pace of scientific advances mean that it will not hold true forever.

CASE STUDY 18: ALGAE PRODUCTION, ARIZONA, USA

Figure 57: Experimental Spirilina algae production races in Arizona

In Arizona, Ron Henson is part of a syndicate of investors and operators developing commercial scale algae production. The company has already set up a pilot plant in the Arizona desert to examine a range of innovative production techniques including an automated V trough pond creation machine and alternative mixing and aeration systems. The company's ambition is the development of a major project, in co-operation with a native Indian community, to develop an integrated anaerobic digestion and algae production and animal feed processing facility on 160 acres of reservation land outside Phoenix, Arizona.

The company is very aware of the significant investment currently being made into developing algae technology. Much of that investment is focussed on developing production systems that will allow high lipid algae species to be grown commercially for biofuel production. A lot of high profile organisations including the Department of Defence and international agro technology companies are chasing the holy grail of biofuel from algae. The attraction is obvious when you consider how algae has the potential to produce biomass yields 100 times faster than conventional plant species. It is also a way in which some of the most unsuitable locations for agriculture, due to soil degradation, can be fully utilised.

Ron and his colleagues are less ambitious because they intend to make use of their collective experience of growing Spirulina algae which is already produced on a commercial scale, as a health food product.

In the world of algae Robert Henrikson is a superstar. He has worked in the industry for 30 years and was the founding director of the world's largest Spirulina farm Earthrise. Henrikson is very positive about the Henson plans describing them, "As a scale which could empower farmers who are on the ground floor in terms of farm size". Henrikson firmly believes that algae can be used to transform health, hunger and the environment with its unmatched protein content (62%) and total nutrient package. After 30 years of developing microalgae's global output has reached over 10,000 tonnes, but algae production costs remain high limiting the current market for algae products to high value nutraceuticals, food supplements and speciality feed supplements. The billion dollar investments taking place in algae biofuel at the moment could be a game changer that results in significant reductions in production costs.

9.0 CONCLUSIONS & RECOMMENDATIONS

9.1 The End of Sustainability

The world has ceased to be sustainable; this was quantified by the 'Global Footprint Network' who can be quite specific that it happened in 1976. Yet few people are aware of this despite the fact that almost every service, product, idea or activity seems today to carry the qualification 'sustainable'. Too often the concept of sustainability focuses on its most basic elements, carbon being by far the most common. This ignores many of the other complex strands that make up sustainability. Policies need to be more holistic, they must address global food security, limited natural resources and climate change and mitigation. Concentrating on single issues such as carbon creates unintended consequences and fails to ensure the deployment of many latent opportunities within agriculture to improve sustainability.

9.2 Sustainability Metrics

Unless we measure it we cannot address it, despite being one of the most frequently used concepts there is no commonly held measure or unit of sustainability. Agriculture should seek to determine an agreed measure of sustainability, in doing so we need to be prepared to abandon the established dogmas which have promulgated activities that have taken us beyond sustainability; we need alternative values that can incentivise a return to one planet living.

9.3 The Population distraction

All too often the focus on the growing world population diverts attention from the real issues. We are set on a course which will inevitably result in 9 billion people on the planet by 2050, and probably 10 billion by 2060. However that inevitability is the result of trends which have already been disabled. Our focus should not be on halting population growth per se, that opportunity has passed us by already, but on how we deal with the resource requirements that the current 'blip' in numbers will demand.

9.4 Latent Potential

For the UK and much of the industrialised world agriculture is now mature, there remain few big wins in terms of productivity, such agriculture is characterised by stagnating or even falling production and a shift in emphasis from production to refining efficiencies and minimizing the environmental and social impact of the industry. The potential to feed the additional 2 billion in the next 40 years will not come from the industrialised world. The 9 billion will rely on the huge largely untapped production potential of many of the developing regions.

9.5 A Role For UK Farmers

UK farmers possess considerable skills and resources to develop world class agricultural operations. In the UK these skills are constrained by limited access to production resources particularly land and labour. In many other regions land and labour are abundant but expertise and investment is limited. There seems a significant reluctance to encourage UK farmers to explore opportunities beyond their own boundaries, a sense of guilt captured in the phrase 'land grab' perhaps a remnant of Britain's colonial past seems to pervade. And yet a lack of domestic food production policy that results in reductions in food self-sufficiency is essentially land grab by proxy as the UK demands more food from developing regions to offset its own falling production. Other countries have less such sensitivity and are busy securing under-utilised resources across the globe, in many cases they institute production systems, environmental practices and social attitudes well below the level that would be applied by UK operators. We need government to help UK farmers not only develop markets but create strategic links that will allow investment in developing countries. Where this is done correctly it will bring food security, economic and social development. If we avoid this approach less philanthropic nations will dominate these regions.

9.6 A Diminishing Land Base

Global agriculture is driven by agricultural land which is being lost at an alarming rate. The result is that the industry will need to learn to produce more from a much smaller resource base; this has been described as 'sustainable intensification'. In many developing regions land tenure and endemic corruption desperately require reform in order that their potential can be realised.

9.7 The Great Nutrient Pillage

Nutrients drive all forms of agricultural production but they are also one of the main causes of environmental damage associated with agriculture. Nutrients like other finite resources should be subject to the same ambitious recycling targets. Not only could this address the issue of supply security but also some of the problems associated with nutrient loss into the environment. Resources should be provided to develop innovative solutions to the retrieval of nutrients from waste streams that can be recycled back to agriculture.

9.8 Research and development

Throughout the world agricultural R & D is poorly equipped to deal with the challenges of sustainability. Of particular concern is the lack of proper integration of disciplines, longer term investment and the interconnection of researchers and end users. We need to move away from an emphasis on individual careers of researchers and encourage the creation of cross disciplinary research groups.

In the UK we desperately need the re-establishment of strategic and applied research capability which has largely been dismantled in-favour of basic research and knowledge transfer. This approach limits the movement of discoveries from the laboratory to the farm.

9.9 Invest

The last green revolution created huge advances in the food security of mankind. I have seen huge amounts of latent potential to create a 21st century green revolution but it requires a huge investment in money, innovation and political will to address many of the intractable issues around the world that are locking people in poverty and hunger. From a UK perspective we have skills and technology that could contribute around the world.

9.10 Policy

As food prices continue to reach new heights the EU should be focusing on food security through production, not imports. Instead, the most recent CAP proposals seem to be taking us further down the road of policies that will reduce outputs. While greening measures are important they need to be measured and proportionate otherwise they will simply export the environmental impact of food production. One of Europe's most unsustainable practices is the propping up of unproductive agriculture through subsidy and the suppression of science through Luddite attitudes. True sustainability requires investment in productivity and food security across Europe.

10.0 A NUFFIELD ADVENTURE

For two years, my life was dominated by my Nuffield Adventure. It let me step out of the frenzied existence that my life had become and let me for the first time in probably twenty years indulge in real thinking time. Those many months travelling to the corners of the planet allowed me clarity of purpose which I had lost, it can be a struggle to retain it in the turmoil of daily life but my Nuffield showed me its importance, I have learnt how important it is keep that focus central and avoid being diverted by distractions.

It was undoubtedly one of the greatest challenges of my life, but with every obstacle came a growing belief in my own ability, the sense of self assurance that it has given me leaves me unperturbed by all but the most formidable challenges and hungry for more.

I set out on my Nuffield hoping for a life changing discovery, naively I thought that would probably be in the shape of some piece of technology that I might be able to exploit in the UK, and indeed there have been many great ideas that I have been able to bring home, ideas ranging from the simple such as frost protection of water supplies through to the more advanced such as nutrient partitioning of effluents.

To my surprise the real discoveries were the phenomenal people I met. I have never found difficulty creating innovation ideas come readily. It was the constant interaction through my Nuffield with inspirational and motivated individuals in all walks of life that showed me what can be achieved with ideas.

I realise now that success correlates to the people who surround you, by expanding your boundaries you ensure exposure to the most inspirational of operators, travel especially creates these opportunities as does the wonderful network that Nuffield creates, something which I regularly now make use of and hopefully in turn contribute to.

11.0 ACKNOWLEDGMENTS

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