CLIMATE CHANGE AND AGRICULTURE.

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1. EXECUTIVE SUMMARY.

This report will take you through what I found to be the major issues of climate change and how these issues will impact on the profitability of agriculture and how agriculture in turn will impact on climate change. In doing so, a lot of the information in this report and the methods that I have outlined that agriculture will need to do to survive climate change is taken from a world wide perspective. The degree of impacts that climate change will have on our society, will not have been seen since the industrial revolution. Of all the issues that confront us today that are classified as global issues, climate change has the ability to affect us in the most dramatic way, by affecting every living organism on Earth.

I have taken a detailed look at the findings of the various research groups that have been working on climate change and its potential effects on agriculture and our society. One of these groups is the "sceptic" movement that raises issues of whether climate change is actually happening or not and if the cost of fighting climate change is actually higher than the effects it could have on our society, the environment and its ecosystems

When I left Australia to study my chosen topic of climate change and its effects on agriculture I felt sure that most of the answers to my question would be found by talking to climatologists and plant pathologists, it wasn't until I met an economist in Germany that I realised the major role economics would play in determining what crops would be grown where. Just because a climatologists says a crop can or can not be grown in a certain area because it is now receiving more rainfall it doesn't mean crops will necessarily be grown there. In the future what will ultimately decide where crops are grown is whether it is profitable to grow them in that region.

The whole issue of climate change can become a topic that presents a very gloomy future for our planet. However, I have discussed a number of ways that we can reduce, mitigate, and live with the effects of climate change. I believe we could make agriculture a big part of the solution, instead of it being a big part of the problem. This could then lead to an even more profitable future for agriculture. In saying this there are a number of obstacles to be negotiated before this could become a reality.

2. ACKNOWLEDGEMENTS.

Firstly I would like to thank my principal sponsors the GRDC (Grains Research and development Corporation) and QANTAS for providing the Nuffield Farming Association with the funds that gives farmers like my self an opportunity to experience the incredible world wide network of Nuffield Scholars.

I would like to thank my parents for their encouragement to apply for the Nuffield Scholarship and their continued support. They also looked after the farming operations whilst Martine and I were away. Without them it would not have been possible for us to travel together for such a long time.

I would also life to thank my parents in law Vanne and Judy Trompf for their support and enthusiasm for my topic. Their proof reading and input has been invaluable.

There are also a lot of other people I would like to thank who helped Martine and my parents while I was away on the first half of my trip. Matt Foster's weekly reports on the cropping were a great help. Also the Lee family and Len Bayliss for helping Martine start our sorghum harvest smoothly. Also to Peter Slade who kept in contact with Martine and made it so much easier for her to organise the timely spraying of our crops.

Without Cam and Rocky McKellar's support I would not have had the courage to apply in the first place. Thank you for your persistence Cam it took you nearly ten years to persuade me I wasn't indispensable at home and that I did have the time to go. Thank you for your persistence.

Special thanks must go to Mrs Vallance, you will never know how much you helped me to get this scholarship, your help, support and friendship I will never forget.

I would also like to thank the selection committees of Australia, New Zealand, England, France and Canada for selecting such a great group of people to spend eight weeks with. I truly have made life long friends, we proved you can't have too much fun!

Thank you to The Nuffield organisation in the UK for a well organised tour of England and Europe, and to the Dean, John Alliston, and all his staff at the Royal Agricultural College at Cirencester thank you for the generous use of your facilities, and the hot tip in the fifth at the Cheltenham Races.

I would also like to thank my host family in the U.K, James and Barbara Nelstrop. James organised and attended the first meeting at the University of East Anglia, which was a great way to begin studying my topic. The "home" they gave me in England upon my arrival from Asia (with a cold) and again in September with Martine makes up some very happy memories of our travels.

On the leg of my scholarship that I was studying my topic of climate change I met with a lot of people who were very generous with their time and without their input this report would not have been possible. Some of these people are;

Terry Francl from the American Farm Bureau whose hospitality at the Carbon Conference in Iowa was good fun and his information has proved to be vital in helping me write this report.

Dr Robert Kauffman, from the Centre of Energy and Environmental Studies, Boston University, who started me thinking about high energy use in agriculture.

Dr Cynthia Rosenzweig who is the head of the climate impacts group at the NASA/ Goddard Institute for Space studies. Her book, "Climate Change and the Global Harvest", her time and the information she shared with me in New York were instrumental in the writing of this report.

Dr Peter Cox at the Hadley Centre in the UK for the large amount of time he afforded me and for his organisation of some of his colleagues for the most informative "pub" lunch I have ever had. The information that I gained at the Hadley Center proved crucial to the final make up of this report.

The staff at the Bureau de l'Agriculture Britannique, and in particular Damian Phillips, who organised and attended meetings with me in Brussels.

Dr Heinrich Hoper from the Institute of Soil Technology in Bremen Germany who organised a lot of my meetings in Germany and for investing so much of his own time in my topic.

Dr Gernot Klepper from The Kiel Institute of World Economics who helped me see the effects of climate change in an entirely different light.

Finally my most sincere thank you to my wife Martine her support has been incredible the whole way through my scholarship. The way she managed the farming operation was fantastic, especially coordinating the start of the sorghum harvest while I was away on the first leg of my trip. She then doubled as the perfect travel companion on the second leg of my scholarship. Without her friendship, love, and support I would not have been able to make so much of this amazing opportunity that was given to me. Thank you, Martine.

3. INTRODUCTION.

At the time of my interview for the Nuffield Farming Scholarship my study topic was to look at the nutrient cycles in our soils under a zero till farming system. However, soon after I watched the ABC's Four Corners program "Emission Impossible". This program really captured my attention and I immediately thought that climate change had the potential to be the biggest thing to affect agriculture since the Industrial Revolution.

I then started to wonder how the impact of climate change would affect us here in Australia and how other countries would be affected. I believed that we in Australia would be affected in two main ways. Firstly climate change would effect our methods of agricultural production, and secondly by changing supply and demand of the world's agricultural products, that in turn would effect the current trading alliances. For example, it would be interesting if the US became a large importer of grain and the production base of world grain shifted to say, the Middle East.

During my study trip through the USA, Canada, Europe and South East Asia, I learnt that I would be able to gain answers to some of my questions, but others will require a lot more scientific study. As models and predictions always have limitations, I believe that the full effects of a warmer environment, with increased carbon dioxide levels will only be able to be fully understood after we have lived within that environment for some time. Then we will see how farmers and society can mitigate the effects of these changes and adapt to these changes. However, it would be good if we could foreshadow the adaptations we will need to make.

Rather than solely focusing specifically on scientific climatic models in this report, I will also address the action that farmers may take to remain profitable in this new world where the price of energy will become a major cost. The price of energy must rise in order for the earth to sustain life. The current negative effect of high energy use on the environment is not at present factored into the retail price of produce. At the moment agriculture is only seen as a large contributor to total world green house gas emissions, but I believe that agriculture could actually hold some of the keys that will help us as a society to live with climate change, and to help reduce the severity of its impact.

Currently we are a society that is heavily reliant on nonrenewable energy, one where farmers are only seen as food and fibre producers. We need to change our energy source to "green renewable energy", such as ethanol production from plants. Hence, farmers will be seen as not only as food and fibre producers, but as food fibre and fuel producers. Maybe this is how we will remain profitable in the future. Although there are hurdles to be negotiated, I think the time is right for our society to make this change.

4. WHAT IS CLIMATE CHANGE?

a) The Natural Greenhouse

Since before life began, Earth has had its own natural greenhouse, comprising of gases, namely water vapour and carbon dioxide, and in smaller amounts, methane and nitrous oxide. It is this layer that helps keep the temperature of Earth within a life sustaining range. Earth receives enormous amounts of energy from the sun every day, and also radiates it back into space. However, the greenhouse gas envelope prevents the radiation of some of this energy (long wave) back into space. It is predicted that without the greenhouse envelope, the temperature on Earth would drop to -18 C instead of remaining at about 15 C. If the thickness of the layer increases then the temperature may rise (Rosenzweig C., and Hillel, D., 1998). This process is called global warming it is allegedly occurring now and is currently the subject of much scientific and political debate. Figure 4.1 below shows the analogy of the major process that keeps a greenhouse warm to the term "greenhouse effect".

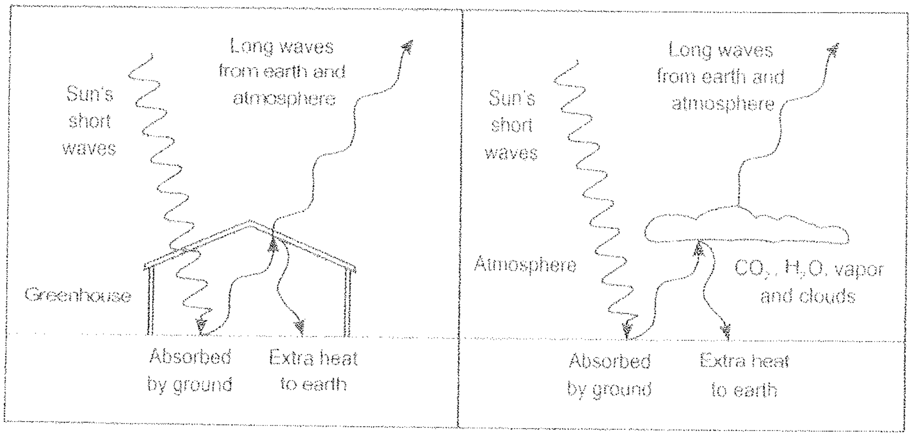
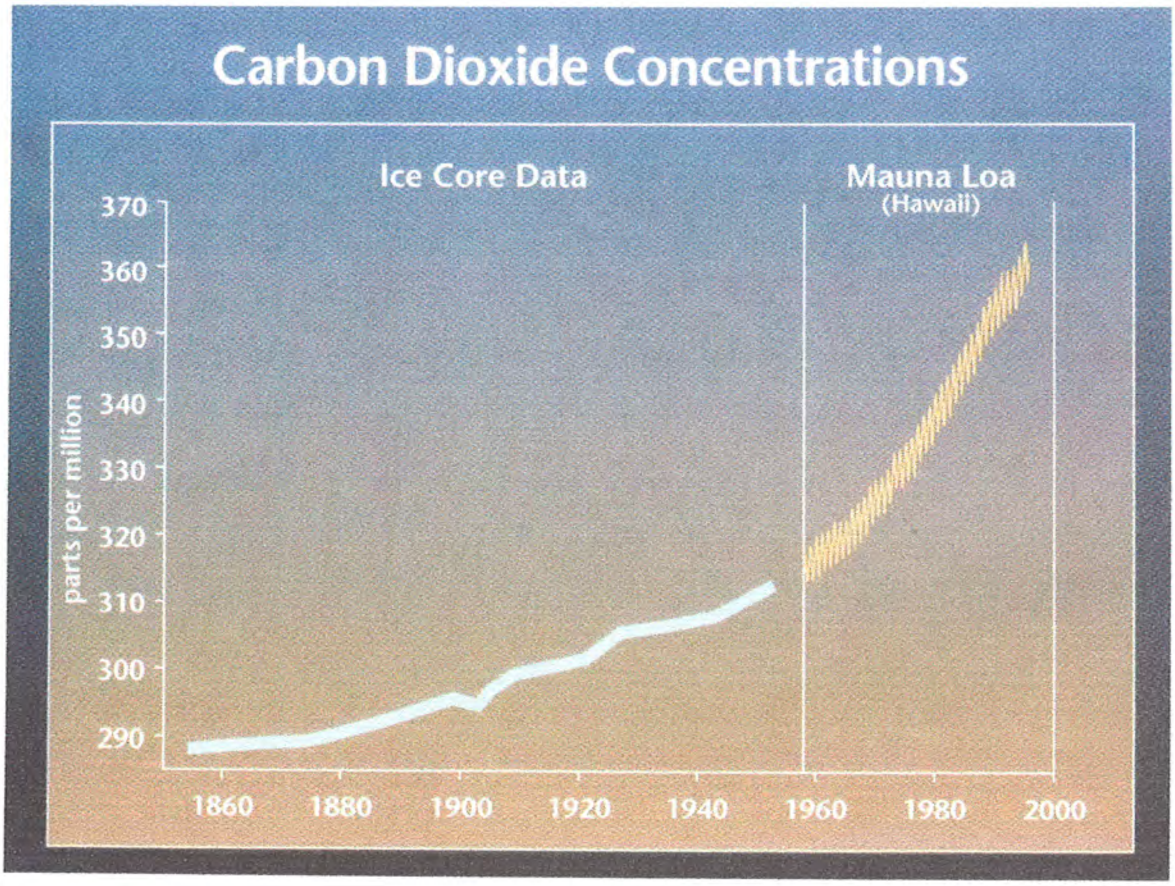


Figure 4.1 The greenhouse analogy (Gedzelman, 1980)

b) What has happened?

As a result of human activities since the industrial revolution, and more particularly since the 1950s the delicate composition of the Earth's natural greenhouse has been changed. This change has taken place at a rate that is much too fast for the Earth's environment, and its inhabitants to evolve to the newly created environment.

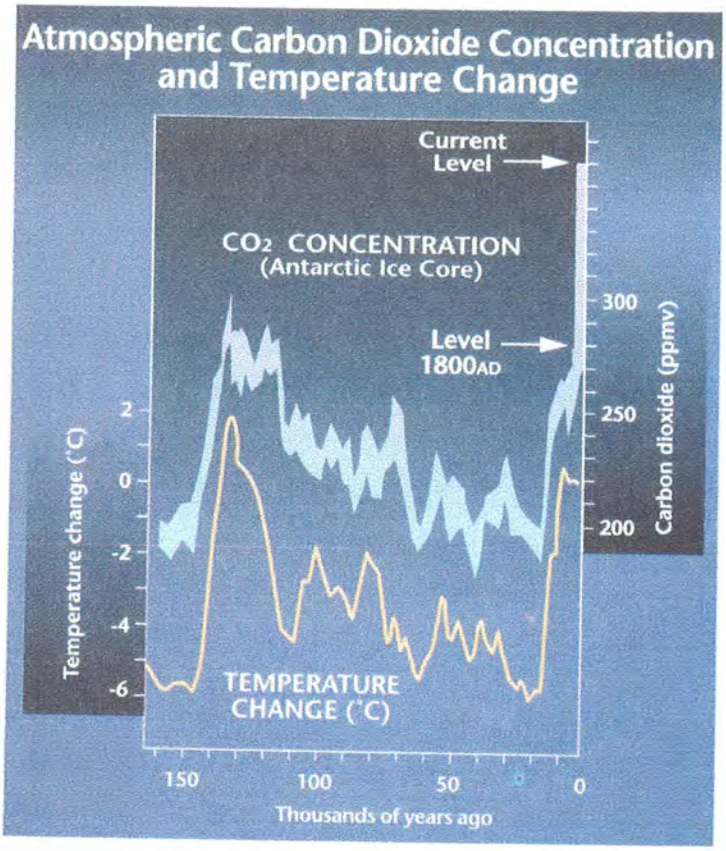
This change to our atmosphere has been created by the releasing of greenhouse gases at a higher than normal rate. Of these gases CO_2 is the gas that has been released in the largest quantities. The levels of atmospheric CO_2, have increased by 30% from 280 to 360 PPM (parts per million) since 1860 .A wide variety of human activities contribute to greenhouse gas emissions. Burning coal, oil and natural gas releases approximately 6 billion tonnes of carbon into the atmosphere each year. By reducing the storage of carbon by trees burning and logging of forests indirectly increases carbon emissions by 1-2 billion tonnes per year (The Office of Science and Technology, 1997). The rate of this increase in carbon dioxide concentrations over the last 150 years can be seen the following graph.



Since the beginning of the Industrial Revolution in the middle of the 19th century, the concentration of carbon dioxide (CO_2) in the atmosphere has steadily increased. Beginning in 1957, continual measurements of atmospheric CO_2 concentrations have been made by scientists at an observatory in Mauna Loa, Hawaii. The seasonal cycle of vegetation in Northern latitudes can be seen in this record: each spring the vegetation "inhales" and absorbs CO_2, and each autumn most of that CO_2 is released back to the atmosphere.

Figure 4.2 Carbon dioxide concentrations (The Office of Science and Technology, 1997).

The graph below shows the effect increased in carbon dioxide levels has on the temperature.



Data from tiny air bubbles trapped in an Antarctic ice core show that atmospheric CO_2 concentrations and temperatures from 160,000 years ago to pre-industrial times are closely correlated. Direct measurement of CO_2 concentration and temperature in recent decades extend this record to the present day, and confirm that CO_2 concentrations have risen to 360 ppm and temperatures have increased 0.5 degree C (1 degree F) over the last 100 years.

Figure 4.3 Atmospheric carbon dioxide concentration and temperature change (The Office of Science and Technology, 1997).

It must also be noted that the emissions and therefore the concentration of other greenhouse gases has also increased at the same time. The methane levels have doubled and the levels of nitrous oxide have risen by about 15% over the same period.(The Office of Science and Technology).

The point that I think is lost in a lot of the media commentary about climate change, is the fact that all greenhouse gases have atmospheric lifetimes that vary from 1.5 years to 50000 years. Not only do these gases have varying life times in the atmosphere, but the way they effect the production of tropospheric ozone (which absorbs terrestrial long-wave radiation, hence acting as a greenhouse gas retaining heat and returning it to the Earth's surface) and stratospheric water vapor will also vary (U.S Environmental Protection Agency, 1999). Global Warming Potential Values are demonstrated in the following table.

GAS	Atmospheric lifetime(yrs)	GWP *
Carbon dioxide (CO_2)	50-200	1
Methane (CH_4)**	12 (+ or - 3)	21
Nitrous oxide (N_2O)	120	310
HFC-23	264	11700
HFC-125	32.6	2800
HFC-134$_a$	14.6	1300
HFC-143$_a$	48.3	3800
HFC-152$_a$	1.5	140
HFC-227$_{ae}$	36.5	2900
HFC-236$_{fa}$	209	6300
HFC-4310$_{mee}$	17.1	1300
CF_4	50000	6500
C_2F_6	10000	9200
C_4F_{10}	2600	7000
C_6F_{14}	3200	7400
SF_6	3200	23900

Table 4.2 Global warming potentials and atmospheric lifetime (US Environmental Protection Agency, 1999).

Note: * 100 year time horizon.

** The methane GPW includes the effects and those indirect due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

5. INTERNATIONAL POLITICAL REACTION.

In 1988 the United Nations General Assembly adopted a resolution that recognised that climate change was actually happening and that its impacts would be felt world wide. This resolution, known as, "resolution 43/53", was responsible for bringing the issue of climate change to the attention of the political world.

The "Intergovernmental Panel on Climate Change" (IPCC) was formed in 1988. Their role is to provide scientific assessments of the problem and to look for possible solutions. In 1990 the First Assessment Report of the IPCC noted that there was an inadequacy of the existing legal instruments, and it therefore recommended that a Framework Convention on Climate Change (FCCC) be set up. In 1992 at the Earth Summit in Rio de Janeiro, the FCCC draft was presented and was subsequently signed by Australia and 153 other states. The FCCC gained a commitment from Annexe 1 countries, (industrialised nations) that they would aim to reduce their emissions to the 1990 level by the year 2000.

The Conference of Parties, (COP) represented the states that ratified the convention, and it was also responsible for undertaking the negotiations on the implementation of the convention. The COP met for the first time in 1995 in Berlin where it was agreed that the commitment to return to the 1990 levels of greenhouse gas emissions by the developed nations was inadequate and there was a need to strengthen their commitment.

Eventually in December 1997 at the third COP meeting (COP3) over 180 nations met in Kyoto, Japan, to finalise negations that would form the bases of a legally binding international treaty. The aim of this treaty was to see a world wide reduction in the level of greenhouse gas emissions. This treaty is now known as the Kyoto Protocol.

In the Kyoto Protocol, Australia is classed as an Annexe B country, and therefore is to restrict its greenhouse gas emissions to an increase of 8% above the 1990 level in the year 2010, with a measurement period that extends from 2008-2012.

6. THE POLITICS OF RESEARCH.

Trying to answer the question of what will be grown where, how much will be grown, whom it will be sold to, and for how much is probably the hardest question that could be asked. Funnily enough it is the question that everyone asked me when I told them what my Nuffield topic of study was going to be.

There has been a huge amount of money spent on trying to find out the answers to this question of world food security, but to get a clear cut answer will be nearly impossible. I was continually amazed at the divide that existed between the various researchers involved with this issue. Some of these research groups were: climatologists, plant physiologists, bioclimatologists, and economists. It seemed to me that each group of researchers believes the answer to this question lays in the work that they are doing and they should be getting a larger share of the funding. I believe this is a large cause of the divisions within the research community with the end result being a somewhat fragmented research response.

I was continually amazed at the readiness that a climatologist for example would dismiss the workings of an economist, saying that he or she would not know the first thing about climate change and its effects due to their lack of knowledge about climate. In saying this there has been a lot of books written on the topic where an attempt has been made to marry the varying schools of thought together. However, I usually found that at least one side of academia was less than satisfied with the end result.

I was surprised to get such a divided response to such an important issue. At first it made me frustrated because it was going to be a lot harder to get the answers to my question than I had imagined. Then I became annoyed to see a major issue being bogged down with such politics. Then I looked at this arguing between the leaders in their fields of research as being a symptom of a much larger problem, and not as the problem itself. The larger problem being, that because there are so many variables that can affect the outcomes of any research that is done on this topic, it is virtually impossible to get a concensus.

In the course of my travels through the US alone I collected and sent home more than 14 kgs of information and collected just as much in Europe. It has been very exciting to collate all of this on my return home, and through this process I believe I have been able to decipher the major points of agreement, conjecture, and disagreement and make them the basis of my report.

7. THE SCEPTICS' PERSPECTIVE

a) The costs of the Kyoto Protocol. Is it the way to go?

Like all debates there is always two sides to a story, and this story is certainly no different. It has to be said that nearly all the 'sceptics' I met with were based in the USA. Before we start to believe the evidence the US gives against the occurrence of climate change, I should perhaps mention some reasoning for their viewpoint.

It soon became apparent to me that the Americans' biggest fear in dealing with climate change comes from the costs associated with meeting the Kyoto Protocol (which they are yet to sign). They think that meeting the level of reductions in emissions would see the American economy suffer and therefore they could lose their position in the world as the worlds strongest economy. This could then lead to their quality of life deteriorating. They may have a valid point as I was surprised at the amount of research that showed a huge increase in costs to agriculture and industry by meeting the Kyoto Protocol standards. So if climate change is a myth and if the predictions from their research are correct, their concern may be justified.

The Heartland Institute's policy study, "The Kyoto Protocol and US Agriculture", (Francl et al.,1998), calculates the likely effect the energy price increase, (that would be required by the Kyoto Protocol), would have on the "average US farmer's" net profit . Firstly the impact of higher energy prices (increases equal to 25 or 50 cents/gallon of gasoline) on agricultural inputs is calculated. By using the farm production cost data from the ERS Farm Business Economics Report, 1994, they were able to estimate the results seen in the table below.

Table 7.1
Effect of Energy Taxes on Cost of Agricultural Inputs
(percent increase in cost/unit of output)

	25c/gallon tax	50c/gallon tax
Fuel and electricity prices	25%	50%
Pesticides/chemicals	20%	40%
Fertilizer-corn/cotton	20%	40%
Fertilizer-wheat/soybeans	15%	30%
Custom operations/hauling	15%	30%
Other expenses	5%	10%

Table 7.1 The effect of energy taxes on cost of agricultural inputs, (Francl et al., 1998)

The following table demonstrates the impact higher energy prices have on six representative commodities. The base year is once again 1994 where the average profit per acre for corn was US $99.11. It shows that the adoption of a tax on gasoline of US $0.25 cents per gallon, (approximately 3.7 litres), would reduce net profit of corn from U.S $99.11 to US $76.70 per acre, and a US $0.50 increase would lower net profits to US $52.50.

Table 7.2
Impact of Higher Energy Costs on Agriculture
(dollars per acre/hundredweight)

	Base	**Low**	**High**	**Base**	**Low**	**High**
		Corn			**Cotton**	
Variable cash expenses	147.08	169.92	193.65	276.95	312.17	347.38
Change		15.5%	31.7%		12.7%	25.4%
Net Profit	99.11	76.7	52.5	143.36	108.14	72.93
Change		-23.0%	-47.0%		-24.6%	-49.1%
		Soybeans			**Wheat**	
Variable cash expenses	75.76	86.11	96.45	54.58	61.87	69.15
Change		13.7%	27.3%		13.4%	26.7%
Net Profit	100.91	90.56	80.22	25.48	18.19	10.91
Change		-10.0%	-20.5%		-28.6%	-57.2%
		Hogs			**Milk**	
Variable cash expenses	38.44	40.32	42.41	11.35	11.78	12.2
Change		4.9%	10.3%		3.8%	7.5%
Net profit	4.7	2.82	0.73	1.6	1.17	0.75
Change		-40.0%	-84.%		-26.9%	-53.1%

Table 7.2 The impact of higher energy costs on agriculture (Francl et al., 1998).

Costs and profits can already be seen in the previous table, however, Francl et al think these figures are so important they demonstrate them in a separate table the impact the Kyoto Protocol will have on individual farmers. These figures are shown in the table below.

Table 7.3
Effect of Kyoto Protocol on Individual Farmer's Costs and Net Profit

Commodity	Effect on Costs		Effect on Profits	
	25c per gallon tax	50c per gallon tax	25c per gallon tax	50c per gallon tax
Corn	15.53%	31.66%	-23.05%	-46.99%
Soybeans	13.66%	27.31%	-10.26%	-20.50%
Cotton	12.72%	25.43%	-24.57%	-49.13%
Wheat	13.36%	26.69%	-28.61%	-57.18%
Hogs	4.89%	10.33%	-40.00%	-84.47%
Milk	3.79%	7.49%	-26.88%	-53.13%

Figure 7.3 Effect of Kyoto Protocol on individual farmer's costs and net profit (Francl et al., 1998).

It can be seen from the figures and table above there is a lot at stake for agriculture in the climate change debate. This is even truer when you consider that the American agricultural sector is responsible for approximately one fifth of US's total green house emissions and the US is in turn responsible for approximately one quarter of the world's total green house emissions. It is for this reason there is a lot of world wide interest in what directions the US take in regard to their ratification of the Kyoto Protocol particularly article 3.4 (this relates to agricultural soils been used as carbon sinks).

b) Is climate change happening?

A lot of the sceptics' points are very convincing and definitely warrant closer attention. They make the point that the reason why temperatures are showing a rapid increase is mostly due to urban development. The temperature records of London since the seventeenth century show a steady rise in the average temperature up to the present day. The sceptics say this is because London has been highly developed (particularly since the 1800's), and this has increased the amount of concrete and bitumen that act as thermal heat banks, trapping heat during the day and then releasing it at night (Heartland Institute).

This theory is backed up with the statistics that show the increase in average daily temperatures is caused by an increase in the average daily minimum temperatures. They argue that if the increases were due to climate change we should see the average daily maximums increasing, not the minimums increasing.

During my study trip I soon found myself believing in the reality of climate change one day and the next day I was not so sure. However, there is one fact that remained difficult to argue against, that is the levels of carbon dioxide in the atmosphere have increased since the 1800s. Back then the CO2 levels were at a concentration of under 280 ppm (parts per million) but they have now risen to a level of over 360 ppm today, see figure 4.2, (The Office of Science and Technology, 1997). I believe it is this statistic that stands up to nearly all forms of scrutiny and is probably the most accepted fact on both sides of the climate change argument. Although everyone agrees that carbon dioxide levels are actually rising there is still debate as to how this increase will affect life on Earth.

c) Is it all bad news?

Some argue that the negative effects of climate change will be out weighed by some perceived potential benefits. A good example of this is the effect that rising temperature and rising carbon dioxide levels will have on plant growth. Plants will grow faster in such an environment, so it said that this could increase crop yields and therefore improve the profitability of grain and pasture production. Superficially this theory seems logical, however like all things in nature it is not that simple. Changing one aspect of the life cycle, such as increasing plant growth, will soon effect other organisms and thus upset the intricate balance of nature. In addition to this the other obvious problem is that by increasing the carbon dioxide levels in the atmosphere we will also increase the intensity of the greenhouse effect. This in turn will lead to increased temperatures and create a volatile climate, so the benefits that increased carbon dioxide levels could have on plants would soon be negated.

d) The approach the "Sceptics" say we adopt.

The following is an extract from The Heartland Institute's policy study, "The Questionable Science Behind the Global Warming Scare" by Joseph Bast, Number 89, October 30, 1998, Chapter 7.

The best strategy to pursue is one of "no regrets".

"Some environmentalists call for a "save the day" strategy to stop global warming saying it is better to be safe than sorry. Such a position seems logical until we stop and think: Immediate action wouldn't make us any safer, but it would surely make us poorer. And being poorer would make us less safe.

Researchers have found a close relationship between a nation's standard of living (its wealth) and many measures of public health and safety. Whether societies are able to invest more in things that ensure safety, such as guardrails on highways, vaccines against disease, and safe drinking water. Simply put, wealthier is healthier.

The "save the day" strategy will definitely make us poorer, to the tune of hundreds of billions of dollars each year. If that money is no longer available to purchase safety-enhancing devices, plainly we will be less safe as a result of our efforts to "stop global warming." We would, moreover, be denying our children and grandchildren of the capital and new technologies that would enable them to live better lives than we did.

CO2 stays in the atmosphere for decades, meaning each year's emissions are only a small percentage of the total amount of CO2 in the atmosphere. Consequently, immediate large reductions in emissions have relatively small effects on concentrations of greenhouse gases.

Whether emission reductions occur now or in thirty years from now, they will have the same overall impact. If it proves necessary to make reductions, the cost of making reductions later, after new technologies now under development become available commercially and after current capital stock has come up for replacement, is likely to be much less than the cost of making reductions today.

The best strategy is to invest in atmospheric research to determine whether a genuine threat exists, and to invest in reducing emissions only when such investments make economic sense in their own right. Reduced emissions, then, are an added benefit.

This strategy is called "no regrets". It positions us to respond quickly to bad news while avoiding the mistake of spending too much, too soon, preparing for a threat that never materializes. Some of the activities that would form part of a no-regrets strategy include:

- *Fund research on the effects of higher CO2 concentrations on plants and agriculture.*
- *Break the federal monopoly over global warming research, which currently has the effect of phasing out inefficient machinery.*

• *Lower capital gains taxes and make other changes to tax policies and regulations to encourage new investments in capital and technology, thereby speeding up the process of phasing out inefficient machinery.*

•*Repeal regulations that stand in the way of energy efficiency, such as restrictions on operating small businesses at home, and zoning ordinances that lead to urban sprawl.*

• *Carefully target investments where they are needed to accommodate climate change. For example, higher sea levels, should they occur, could be addressed by modest improvements to dikes and seawalls in some areas, and by relocating homes and businesses in other areas. This cost spread out over the course of a century would surely be less than the cost of attempting to prevent climate change through energy taxes or emission caps.*

•*Replace "command and control" regulations, which tell businesses what they must do to reduce emissions, with flexible and incentive based rules that allow the use of lowest cost options. This would end the pure waste of billions of dollars a year, allowing some part of that savings to be invested in research or ways to accommodate climate change.*

The alternative to the Kyoto protocol is not to do nothing. The "no regrets" strategy is a comprehensive alternative that promises much superior results without the enormous social costs and losses of liberty that would accompany implementation of the Kyoto Protocol."

The Sceptic movement has a lot of very good arguments. I have only addressed a few of these in this report so far. I believe I can put some of these arguments to rest in this report, but others I found hard to lay counter claims to. However, the one thing that kept coming back to me is the fact that today the world uses 75 million barrels of oil a day. In the 1970s the developing countries accounted for 26% of the total oil demand. Now their use is closer to 40% and this figure is likely to continue growing with their population. (figures sourced from the BBC NEWS web page 24-03-00). Surely with figures such as these something somewhere has to happen. Whether we can afford the sceptics' wait and see approach as seen in the "no regrets strategy," remains to be seen.

8. CHANGES IN THE WEATHER

Water is without doubt the most critical resource to life on Earth and there is a limited supply. One of the first impacts of the greenhouse effect is to create a warmer environment this will lead to the speeding up of nature's hydrological cycle. With higher temperatures there is higher evaporation rates and thus more moisture in the atmosphere. A warmer, moister atmosphere is a more volatile one, so in this new environment the cycles of floods, droughts, extreme heat and cold will still take place, however it is thought the frequency and intensity of such events will increase.

Our family farm is situated in Northern New South Wales and since the mid nineties we have experienced an increase in the frequency of extreme weather when compared to our weather history since the 1920s. My father has told me that when the 1919 drought broke our neighbour measured 475 mm of rain (19 inches) in eighteen hours, and this was the first recording of any significant rain for over twelve months. An event of this magnitude has not been recorded in our area since. Whilst we have still obviously had droughts and floods we haven't seen them on such an extreme and frequent scale, that was until the mid 1990s. Our average rainfall is 650 mm (26 inches) but in 1998 we had 1025 mm (41 inches) of rain. In late October 2000 we received over 300 mm (12 inches), nearly half our yearly rainfall in one week. This was followed by three months of no rain and temperatures in the low to mid 40s and now just 200 km north of us they have had over 400 mm (16 inches) in four days. Maybe these incidents could be an indicator of the increasing frequencies of extreme weather events.

In the year 2000 the United Kingdom also suffered from at least two major flood events that brought wide spread devastation to farms and townships. The US has also experienced a very unusual weather this winter. On my trip my wife and I visited a large Simmental stud in northern South Dakota, their reports about their winter this year makes it sound like climate change is well under way, they wrote; *"we've had real cold weather and now snow, in early January it warmed up and melted most of the ice and snow. Now we have more ice and snow 5-6 inches of snow again. We have to feed more now."* We received this letter in late February. In northern South Dakota the winters can only be described as extremely cold especially by Australian standards, with temperatures regularly below -40 F with the wind-chill often droping the temperature below -80 F. With such cold temperatures and being this far north in the US it is very unusual that they get a partial thaw in mid winter. This change in the weather has detrimental effects on an agricultural system that it needs a continual freeze throughout winter. Although this is only anecdotal evidence, it is collected from very different parts of the globe.

I am not necessarily saying that all the events described above are solely due to climate change, however if they were to repeat themselves in the next few years we would have to really wonder what else could be causing such a frequency in extremes.

9. THE CLIMATOLOGISTS' PERSPECTIVE

In the previous chapter I gave an example of the complex interactions that are created when the atmosphere is manipulated at a rate that is quicker than it can adapt to. In this chapter I will expand on a lot of these actions and reactions and outline a lot of other effects that climate change could have on our planet and therefore our society.

One of the hardest variables to deal with in any models is the effect that mitigation could have on either reducing the affects of climate change or increasing our ability to live with it. For example will we be able to breed new varieties of crops to cope with the changes in climate? What new methods of farming will be developed? A great example of farmers currently adapting to weather limitations (and not so much climate change), is the development of zero-till. This practice means crops can be grown with less rainfall. One effect of this is that the Western New South Wales cropping belt has moved even further westward.

Another limitation of climate models is that it's not climate alone that dictates where a crop will be grown. It is predicted in some models that in Australia the rainfall will move westward and so too will the cropping belt. However, I think this expansion westward of the cropping belt will be hindered by two things. Firstly by the soil type that is found beyond Cobar and secondly by legislation like the Native Vegetation Act SEPP 46 in New South Wales.

When predicting the impact climate change will have on crop growth and production, there are a huge number of variables that have to be taken into account before we can make an accurate assessment.

It is the variation in timing of weather events that makes the prediction of the world's food security a very difficult task. The issue of food security is one of many major issues to be addressed in a changing environment. The others are; water availability, the spread of diseases and the cost of repairing the damage to infrastructure caused by extremes in weather.

a) Crops and Food Security.

Another aspect that needs to be addressed when trying to understand the world's future food supplies is, which crops will we be growing in the future environment that we could find ourselves living in. I met with Dr Cynthia Rosenzweig, a professor at the Goddard Institute for Space Studies in New York, and she referred me to a very interesting point that she made in her book, "Climate Change and The Global Harvest", namely that plant species respond differently to carbon dioxide levels. This difference is caused by the different ways that photosynthesis occurs in the plant. Some species of plants are referred to as C3, this is because the first sequence of biochemical reactions has three carbon atoms, (because in C3 plants a fraction of the CO2 is reoxidised after photosynthesis), whereas in other plants, known as C4 plants the first product contains four carbon atoms. At the current levels of CO_2 (approximately 350 ppm) the crops known as C3 (such as wheat, rice, and soybeans), exhibit lower rates of net photosynthesis than C4 crops (such as maize and sorghum), this is because the losses to photorespiration in C4 plants are minimal. As C4 crops (developed primarily from tropical grasses) have already adapted to the current CO2 levels they are less likely to be affected by a CO2 increase. Thus in general C3 crops are more responsive to CO_2 enrichment than C4 crops. They may therefore become more competitive than C4 plants in the future. We may not only see an increase in the area sown to C3 crops in the future but we could see the C3 weed species become a bigger problem as well, particularly in our C4 crops that don't respond as well to the higher levels of CO_2 Rosenzweig, C and Hillel, D.1998).This is demonstrated in the graph below.

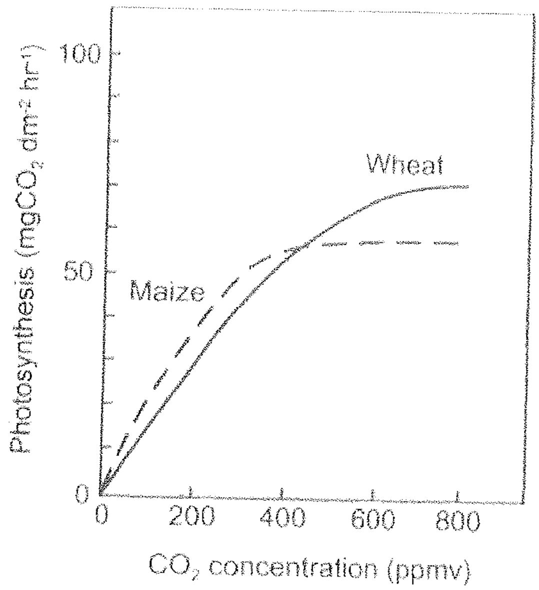


Figure 9.1 Effect of atmospheric CO2 concentration on rate of photosynthesis of maize and wheat in controlled environment experiments (Akita and Moss,1973)

In addition to the change in ratio of C3 to C4 plants in the future, it is predicted that overall cereal production will be reduced. If there is no change in the climate it is estimated that production will grow from about 1,800 mmt (million metric tonnes) in 1990 to about 3,500 mmt in 2050, this production will meet global food requirements throughout the period. However, climate change scenarios will lead to world cereal production being progressively reduced by the 2050s. It is estimated that by the 2050s the world could experience a shortfall of 90 mmt. Food prices are predicted to increase by 17% and the number of people at risk of starvation is projected to increase to 30 million by the 2050s, due to climate change (Parry et al., 1998).

The map below shows that by the 2050s the crop yields are expected to increase in the high and mid-latitudes but are expected to decrease in lower latitudes. These decreases in yields are seen in Russia by the 2020s, and in Canada by the 2080s. Western Africa and tropical South America appear to be the worst affected, for example in Africa it is estimated that cereal production will be reduced by about 10%, placing 18% more people at risk of hunger. The yields in some regions, such as Canada and Australia, may initially increase but they will decrease over time, due to the changing balance between the positive effects of the increase in the levels of CO_2 and the negative effects of moisture stress (Parry et al., 1998).

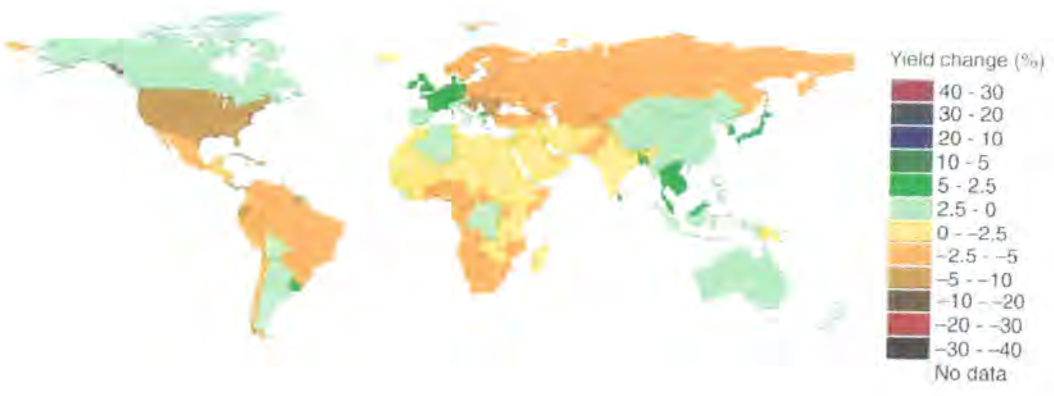


Figure 9.2 Potential change in yields of cereals (wheat, maize, rice) for the 2050s, including effects of CO2 (Parry et al., 1998).

b) Water Availability.

Approximately one third of the world's population lives in countries that already experience water stress (countries that use more than 20% of their total annual water supply are generally defined as water stressed). It is estimated that by the year 2025 as much as two thirds of the Earth`s population (which will by then be a lot larger) will be exposed to water stress.

The first map below shows the estimated change in 30 year mean annual run off by the 2050s. This is compared to the baseline period 1961 to 1990. The runoff increases in the high latitudes, South East Asia and some equatorial regions, but decreases substantially in Europe, most of Africa, the Middle East, eastern North America, and much of the Amazon basin. In eastern Europe, northern United States, and some parts of eastern Asia the amount of precipitation that falls as snow will be less due to the increase in temperature. Therefore, less water will be stored on the Earth's surface as snow. This will then lead to an increase in the river flows in winter and a decrease in the spring flows (Arnell, N. 1998).

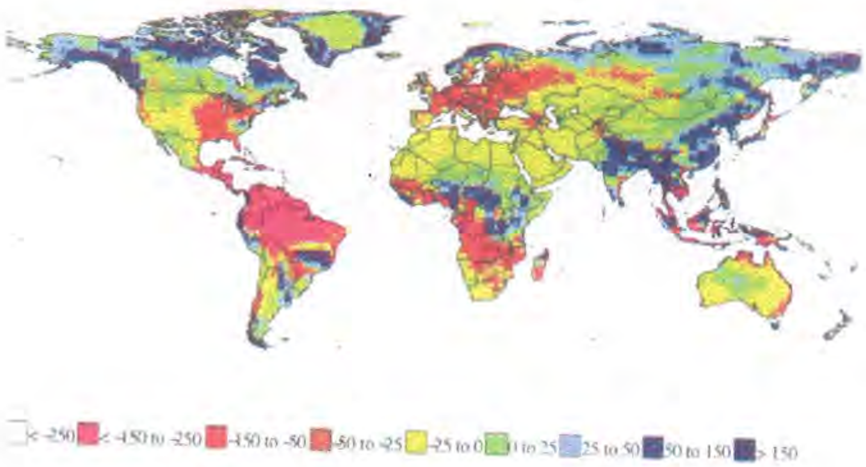


Figure 9.3 Estimated change in 30 year mean annual runoff (mm/yr) by the 2050s, compared with the baseline period (Arnell, N. 1998).

Figure 9.4 Change in water stress, due to climate change, in countries using more than 20% of their water resources (Arnell, N. 1998).

The second of the two maps shows the effect of climate change on water stress by the 2050s, relative to the effects of population growth, and indicates that water resource stress in many of the poorest countries would be exacerbated by climate change. Climate change would lead to an additional 66 million people living in countries that use more than 20% of their potential resource by 2050, and an additional 170 million people would be living in countries using more than 40% of their water resources (Arnell, N. 1998).

The availability of water, and the timeliness of its supply to my mind is the biggest hurdle that we face in trying to get an understanding on how climate change will effect food security for the world. As the average temperature increases the evaporation and transpiration rates of plants will also increase. The issue is how often, and at what intervals in a plant's growth cycle, will it be subjected to longer periods of stress and wilting. Obviously if the stress occurs at flowering and grain fill it will have a greater impact than if it occurred at the vegetative stage of growth. The reduction of wheat yield due to water stress during crop development can be seen in the following diagram.

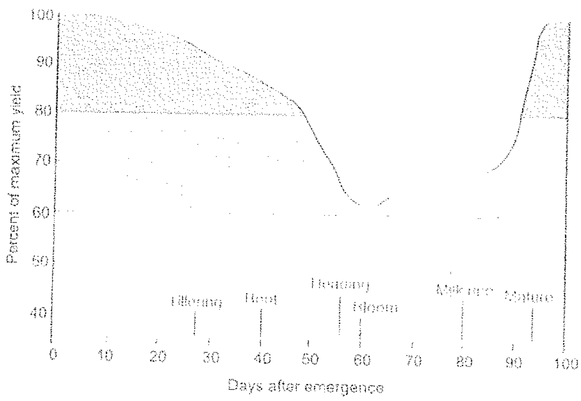


Figure 9.5 Effect of water stress at various growth stages on wheat yield (Bauer, 1972).

Moisture stress can also come in the other extreme form of water logging. However I believe the biggest issue may well be the quality of the grain that will be harvested, and whether it is suitable for human consumption. Rainfall from the flowering stage to the harvesting of the grain can have a vast array of effects on quality. These can range from leaf diseases that stop the plant from filling the grain to the growth of smuts and moulds that can be toxic to both humans and livestock. For example imagine the shortage of grain there would be if we had two more seasons like the 1998-2000 wheat seasons in the grain belts of Southern Queensland and Northern New South Wales. The amount of yield that was lost because we could not get onto our country due to the wet weather will never be able to be calculated. The extremely wet conditions also caused many grain diseases that meant the grain was not suitable for human consumption.

<u>c) Human Health.</u>

The issue of food security, and the risk of increased occurrence of starvation in the future, as a result of climate change, is one that is very hard to calculate and will probably be the focus of more research in the future. While the impact of climate change on the total amount of food produced in the world may only be small, there could be large shortages in regions that suffer an extreme weather event at a time that is critical to the production or distribution of agricultural produce.

We have already seen examples of the effects of extreme weather in recent years in Bangladesh, Thailand and the UK. Whilst the impact of such events in developed nations is terrible, it is unlikely to lead to a massive outbreak of cholera or dysentery. By the same token the damage to crops, while it will cause tremendous financial hardship, it is not likely to lead to starvation. In developing nations however, the risk of starvation, disease and the financial losses would be fatal for thousands of people. Another indirect effect of the increasing frequency of extreme weather events will be the amounts of money that will be required for domestic and international aid. This impact on aid money and its supply could prove to be the biggest hardship for developing nations.

A further impact of climate change on human health will come from a change in the distribution and types of diseases that affect us. This is because the environment of the disease carrying hosts such as insects, ticks, and rodents will be extended. A good example of such a disease is malaria. Malaria is the most prevalent mosquito borne disease in the world and currently approximately 40% of the world's population are at risk of infection. When the temperature and humidity rise, as a result of climate change, malaria could have the potential to spread even further, particularly into areas that were once considered temperate zones. It is however unlikely that we will see malaria become prevalent in developed nations as we have adequate surveillance systems and have effective control programs already in place to prevent its spread (Martens, P et al., 1998).

10. THE ECONOMISTS PERSPECTIVE

When I began my trip I was sure that I would find the answer to my study topic talking to researchers of climatology. However, I did not foresee the importance that economics would play in the answer. For example, just because an area receives more rainfall as a result of climate change and it can therefore grow grain, it does not mean that it will necessarily become an established grain growing area. There are many other factors that have to be considered before it becomes "economically" viable to grow crops in a certain area.

a) Energy: A new cost.

The price of energy is expected to keep rising. This is mainly due to two main factors. Firstly the increase in demand for energy will increase the price, and secondly the price of energy will rise due to governmental policies increasing taxes in order to meet the cuts in emissions that they agreed to under the Kyoto Protocol. As mentioned in Chapter 7 the point the sceptics make about the effect that higher energy costs have on the profitability of grain will be even more evident once we are living with climate change. I believe that this increased cost of energy will be the biggest factor to effect the production of grain and therefore the world wide supply of grain in the future environment.

At the Carbon Conference in Des Moines, Iowa, I met Terry Francl a senior economist and commodity specialist with the American Farm Bureau Federation. He has written a paper titled, "Higher Fuel Costs Will Cut Farm Income" (22/6/00). In this paper he states that "every $1.00 US increase in crude oil prices raises annual farm expenditures for fuel and oil by about US$330 million". He also states that "natural gas typically accounts for about 75% of the cash costs of manufactured anhydrous ammonia in the U.S. Energy accounts for half or more of the underlying cash production costs for nearly all of the farms' manufactured (inputs). Therefore, the additional cost, in the form of manufactured inputs, (such as anhydrous ammonia) to the U. S farm sector, for the remainder of 2000 will probably be about US$ 500 million". It is obvious from these statements the amount of energy agriculture uses (both directly and indirectly), and how much the cost of energy effects the price farmers are charged for inputs such as fertiliser. This flows on to have an obvious impact on our profitability.

b) Energy price vs. Agricultural practices.

The increase in our farm energy inputs in the future will have the biggest impact on what crops are grown where and under what agricultural practices they are grown. A good example of such an impact is the changes I have made to our methods of grain production on our family farm. I was made aware of these changes in the efficiency of energy use by Dr. Robert Kaufmann at the Centre for Energy and Environmental Studies, Boston University.

In the early stages of my meeting with Dr Kaufmann, I was explaining to him who I was and what I was studying as my Nuffield topic. We soon got on to the topic of energy efficiency and crop production. I explained to him the changes I had made at home with the introduction of zero till farming, and how we had seen our yields increase, and how we were now growing up to four crops in three years, instead of two crops in three years. I was sure that this would have seen a reduction of energy we used on our property because the change to zero till also meant that we were able to sell our 340 horsepower tractor. Each year it was used for 1000 hours, cultivating 800 hectares of arable land. It weighed over 16 tonnes and consumed approximately 60 litres of fuel per hour. Due to the smaller draft loads required to pull zero till machinery we were able to purchase a 210 horsepower tractor, which is used for 800 hours per year growing over 1100 hectares of cropping land. It only weighs under 8 tonnes and uses approximately half the fuel of the previous tractor.

Dr. Kaufmann then asked me the question, "what do you think has happened to your energy inputs". Feeling sure that I knew the answer I started to quote the above figures. Half way through I realised what he was thinking, even though we had reduced our fuel energy inputs we had indirectly increased the use of energy significantly through increased fertiliser use. With the adoption of zero till we have significantly reduced the effects of water stress on our crops. As a result the lack of nitrogen, rather than moisture, became the biggest limitation to yield, so we began to use nitrogen fertiliser on a regular basis. The production, packaging and distribution of nitrogenous fertilizer generates about 5.5 kg CO_2 per kg N produced (Howden, S. M, et al.1999). The end result of this increase in the use of nitrogen fertiliser is that there is more non-renewable energy used and more greenhouse gas emissions on our, and many other farms in this area. Although I was aware that farming was an obvious user of energy, I hadn't realised the consequence of changing our management system. I didn't realise how much we had increased our energy use until I was made aware of the previously mentioned fact that 75% of the cash cost for manufactured anhydrous ammonia is due to the cost of natural gas. However, we are also producing more grain per hectare per year and in a more environmentally sustainable way, particularly in regard to soil erosion.

An example of how cropping practices are affected by input costs follows. When we were first starting into zero till the price of Roundup 360 was well in excess of AU $300 per 20 litre drum and the price of nitrogen was in the vicinity of AU$ 0.65 cents per kilogram, as a result the costs to fallow land were very high and the cost of fertilizer made up a small component of the over all cost of a crop's gross margin. Such a cost structuring meant that after we harvested our sorghum crop in April we would sow it to wheat within two months. The sorghum yields increased significantly under zero till and as a result when we sowed wheat into the sorghum stubble it was often with less than 500 mm of stored moisture. These wheat crops would normally average approximately 2.5 tonnes per hectare, with a variance from complete crop failure to a yield of over 4.0 tonnes per hectare.

The above cropping practice was worth the risks associated with it because previously the costs of growing the crop were less than the costs of fallowing land (growing no crop). So it was worth the risk to double crop at a yield of two tonnes per hectare as there was still a reasonable profit to be made. However, in the last ten years we have seen a change in our cost structure. The price of nitrogen has lifted to over AU$0.90 cents per kilogram of nitrogen and the price of Roundup has fallen as low as AU$100.00 per drum. This change has seen the attraction of double cropping vanish to a large degree. We now rarely sow a crop unless we have at least 750 mm of stored moisture in the soil.

The above figures show how change in the costs of our inputs has influenced the management decisions we have made here over the last twelve years. The main point to be gained from the above figures is the changes that we were forced to make due to the increased costs of fertilizer that increased the costs of growing a crop (these are the costs incurred from the application of fertiliser or the seeding of a crop, which ever comes first). The thing that helped us remain profitable was the fact that Roundup fell in price so this reduced our fallow costs (these are the costs of keeping your land free of weeds between crops). There was a shift in the input cost structure. Roundup fell, and nitrogen increased in price so with a change in fallowing techniques we were still able to remain profitable. The problem we have to face now is, what will happen to our profitability when, as is predicted, our energy costs increase and this increase flows on not only to fertiliser, but also to fuel, chemicals and other inputs. We may no longer have the scope to change practises as we saw in the above example. This problem is something other grain growers in Australia are experiencing already. Who knows what will happen when energy costs rise even more due to climate change.

c) Price of Energy and Agricultural Commodity Prices.

One problem with primary production in Australia is that if the costs of production go up the price of what we are producing does not necessarily go up to cover the cost increases, this is commonly known as the "cost/price squeeze". If we continue to see the price of energy rise and it has the impact on the profitability of grain production that Terry Francl predicts (as I've outlined in Chapter 7) what will happen to agriculture?

While I was in Germany I travelled to Kiel in the North and met Dr Gernot Klepper from The Institute of World Economics. By the time I met Dr Klepper my primary focus was on what will happen to grain prices and the input costs of producing grain. I was wondering how farmers were going to stay in business, and in particular how Australian farmers could compete in the world market where our competitors were so heavily supported by government intervention and subsequently sheltered from the true increases in energy costs. He explained the economic theory to me of what "should" happen to the price of agricultural inputs and commodity prices as a result of the increased energy costs and climate change policies. My interpretation of what he said follows.

He believes the reduced profitability of growing agricultural produce will see the developed world remain the major producer of the world's food. This is because for farmers to remain profitable in the future they will have to adopt new technology in a large scale (as outlined in detail in Chapter 12) This technology will be very expensive and like most business costs it will be an up front cost. It will also rely on infrastructure already being in place before it can be effectively implemented and thus taken advantage of. Therefore, the developing world will continue to be a large producer of labour intensive manufactured goods, rather than the adopters of technology to improve food production. They should maintain their current level of domestic food production, however, it is unlikely they will become major exporters of food.

Dr Klepper explained to me that the increases in the cost of agricultural inputs must occur in order for agriculture to become more efficient in its use of energy and there by reducing its emissions and contribution to the greenhouse effect. Increasing our input costs in a free market, will reduce the amount of inputs used to produce agricultural goods (in a truly non subsidised market). This will lower yields, thus reducing the overall supply of agricultural products onto the world market and hence their price will increase. This price rise is vital if farmers are to remain viable. However, this increase in the price for our produce must be less than the amount that our input costs have risen. This may sound harsh from the farmer's perspective, as they would be less profitable. However, if the price of agricultural produce rises to a level where it offsets the increases in input costs, the use of high energy inputs would rise again. This would cause an increase of greenhouse gas emissions, secondly it would increase the supply of products and the price will therefore fall again. In this new world of energy price sensitivity it is imperative that the economics behind the above theory are allowed to work. If put into practice this theory must not be manipulated by government policies such as subsidies, and/or sanctions.

d) Subsidies, Profitability and the Price of Energy.

I believe there would be disastrous effects on both the environment and the profitability of non-subsidsed farmers if the world markets were distorted, and farmers in the USA and Europe were sheltered from the true market signals that would be sent by the a fore mentioned policy position. For example if the price of anhydrous ammonia (82% Nitrogen) was to go from A$600/tonne to A$2000/tonne then not many Australian farmers would use it. Their yields would be dramatically reduced. However, the subsidised farmers could still afford to apply nitrogen fertiliser and this economic theory would fail, to say nothing of the Australian farmers! The environment would suffer because there would be no incentive to reduce the emissions emitted in the creation of agricultural products. The producers in non-subsidsed countries would suffer because the small price increase that they would have seen, as a result of some of the cost increase being passed on, would not occur because the market forces that created it would be nullified by the shielding effect of subsidies on market forces.

e) Subsidies in General.

Agricultural subsidies were started in the 1850s in Germany by the Iron And Rye Coalition to protect the German iron industry from British steel and to protect the German rye industry from U.S grain. Since their inception their purpose has being mostly to guarantee the supply of safe and plentiful food.

After having spent so much time in Europe in the year 2000 I believe that the levels of production based agricultural subsidies in the European Union (E.U) will be wound back from where they are today. There are a number of factors that led me to this conclusion, the first being the issue of food safety. At our Nuffield group meetings in Brussels we were told that the money to support programes such as the Common Agriculture Policy can only come from within the European Union itself so the public's opinion of agriculture is vital if the agricultural budget is to keep taking such a large percentage of the E.U's budget. The Common Agriculture Policy currently accounts for approximately 41% of the European Unions budgetary expenditure. The issues of Bovine Spongiform Encephalopathy (BSE) and the human variant of the disease, Creutzfeldt Jakob Disease (CJD) have made a lot of people, particularly those who live in the major cities of the UK and Europe, ask why they are paying such high taxes that support farmers to produce plentiful and "safe" food, when it has recently been proven to be unsafe? There are a lot of other issues that have led to the erosion of public support for the agricultural sector. These range from farmers wanting to close the public foot paths that cross their lands to restrict the access of the "ramblers" to the issue of Genetically Modified Organisms (GMO's) and the perceived public view that all farmers are wanting to grow GMO's.

The second major issue that I believe will put a lot of pressure on the European Agricultural budget is the issue of expansion of the union that will see a further nine member states added to the union. Some of these new states include nations such as Hungary, Poland, Slovenia, and Estonia. These new member states may well be net takers from the European budget. These new member states will need many resources and I believe that these resources are likely to come from the agricultural support budget.

I think that there will still be a large amount of government support for farmers but to help keep faith with, "the tax payers" we will see a reduction in production based subsidies in Europe. However, this could take ten years or more to happen. This shift in payments will see a move away from production based subsidies described as Blue Box payments to environmental subsidies known as Green Box payments. These Green Box payments at the moment are not aimed at solely reducing the greenhouse affect. On the contrary many are aimed at the increasing the habitat for native animals and increasing the aesthetics for humans. If the European Union reduces its levels of Blue Box (production based) payments this will then leave the US by itself in World Trade Organisation arguing for production subsidies and I think this would lead to the US's stance soften so they may also make a shift in policy to more Green Box (environmental based) payments.

This shift in agricultural support payments from production subsidies to environmental subsidies could be seen as good news for Australia, New Zealand and Canada, although it could still create a potential trade barrier. With these extra green box payments it will be easier for the European producers to meet higher standards of environmental and animal welfare guidelines than we could afford to reach in Australia. So the Europeans may drop all forms of import duties and trade barriers, except for one, our products will have to meet the same environmental and animal welfare guidelines that they have in Europe. We will not be able to afford to meet these new guidelines as we are not "subsidised" to do so.

11. CLIMATE CHANGE AND ITS IMPACTS ON AUSTRALIA.

The impact that climate change will have on Australia is three fold. The political impacts on government policies, the impacts of climate change on crop production and future profitability for farmers.

a) Political Reaction

In the early stages of international climate change talks, Australia came under some criticism from other countries about the stance it was taking at the international policy level. One of the first issues was the "differentiation" between nations and the amount of reductions that would be made to greenhouse gas emissions relative to their levels of emissions in 1990. In the early stages of negotiation there were strong views that there should be a world wide reduction in emissions. While this was not disputed, the way that this goal was to be achieved, was largely a matter of conjecture.

Australia was seeking a different outcome. It wanted, "an outcome that differentiates greenhouse gas emission targets, taking into account equity considerations and countries' particular circumstances and available opportunities to limit emmissions......We are arguing that each country should have its own individual target reflecting its particular circumstances, economic costs and available opportunities to limit emissions......the cost to each Australian [to reduce emissions] would be many times the cost to each European " (Department of Foreign Affairs and Trade web page).

Australia got its way with the support of Japan, Norway, Iceland and Russia and as a result it has to limit its emissions to a level of 108% of its 1990 level.

The following text in italics briefly describes which directions the Australian international climate policy has taken since signing the Kyoto Protocol. Signing of the protocol means a country is in support of its principles. The protocol only becomes a binding agreement when a nation "ratifies" the protocol.

The Kyoto Protocol

"The Kyoto Protocol is the first international treaty with binding country targets for reducing greenhouse gas emissions. Under the Kyoto Protocol, 38 developed countries and economies in transition agreed to an aggregate five per cent reduction in greenhouse gas emissions from 1990 levels by 2008-2012. Australia, as part of the agreement, undertook to limit its greenhouse gas emissions to 108 per cent of its 1990 level.

Since the adoption of the Kyoto Protocol, the focus of the work at the international level has been the development of the rules and guidelines to implement the Kyoto Protocol. These negotiations have been complex, with substantial policy differences between the main negotiating groups. Until these rules and guidelines are finalised, it is unlikely that sufficient countries will ratify the Protocol to bring it into force.

It was not possible to reach final agreement at the Sixth Conference of the Parties (COP-6) in The Hague (13-24 November 2000) on the outstanding issues surrounding the Kyoto Protocol. The COP-6 meeting will be reconvened in Bonn, probably in May 2001. In the final stages of the negotiations, Australia, and its Umbrella Group partners (including the United States, Japan and Canada) came close to reaching agreement with the European Union on a number of the key issues, including domestic action, sinks and compliance. Unfortunately, the EU was unable to go forward with the proposed deal at that stage."

Source: The web page of, Department of Foreign Affairs and Trade-Australia
http://www.dfat.gov.au

The following is the speech that the Australian Minister for the Environment and Heritage, Senator the Hon Robert Hill made at the meeting of the Sixth Conference of the Parties (COP-6). I believe it gives an insight into Australia's past and future Greenhouse policy.

Statement to the Sixth Conference of the Parties to the United Nations Framework Convention on Climate Change

Senator the Hon Robert Hill
Minister for the Environment and Heritage Australia

The Hague, 21 November 2000

Since the historic agreement reached at Kyoto in 1997, Australia has begun implementing a comprehensive and ambitious program of domestic action to address climate change.

We are now directing almost A$1 billion to tackling climate change. We have established the world's first national office devoted to tackling greenhouse. We have a program of voluntary cooperation with industry which now includes almost all of our major emitters. We have contracted a carbon broker to direct private resources into enhancing our sequestration through re-vegetation. We have before our parliament a bill to increase the amount of electricity generated through renewable energy, to take the overall percentage to over 12%

of generation. Importantly, we are devoting resources to assisting our Pacific neighbours in assessing and adapting to climate change.

Our package of measures is aimed to encourage businesses and consumers to reduce emissions. Last week the government launched a process to consider market-based incentives for business to undertake substantial early abatement action which would continue to have effect during the commitment period. This is a significant step that could see us drawing down a percentage of our Kyoto target to reward early and ongoing abatement. Further, we have created the Greenhouse Gas Abatement Program, a competitive bidding process for government assistance to reduce emissions, which promises to help us move towards a less carbon intense economy.

Australia has taken the Kyoto outcome seriously. We have acted in good faith to embark upon the task required to meet our commitments. But we must ensure that the rules agreed here faithfully implement the balance carefully struck at Kyoto.

In Australia, we have now reached the level beyond which our domestic response cannot pass without further decisions internationally. Domestically, people are finding it increasingly difficult to understand why, having heard the views of the scientists, and why, having reached agreement at Kyoto, uncertainty remains at the international level.

Australia needs progress on four issues to move forward to ratification. We need flexibility mechanisms that create an efficient market that can achieve low cost outcomes. The rules should not constrain the market so that it would fail to achieve its promise. Secondly, we should seize the opportunity to realise the multiple environmental and economic advantages that sinks can confer, within a framework that ensures a simultaneous focus upon the reduction of emissions. Sinks reduce atmospheric concentrations of carbon, and their potential should be recognized. On compliance, our point of departure should be that countries will wish to comply, and should be assisted in every way to comply. For Australia, the path to ratification will also need to recognize that climate change is a problem whose solution is beyond the means of the developed countries alone. We need to chart a means to include all countries in the task of limiting emissions.

We have come to The Hague to engage in serious negotiations to achieve a substantial outcome that will represent an important step along the path to implementing the Kyoto Protocol. We look forward to achieving this.

Source: The web page of, Department of Foreign Affairs and Trade-Australia

http://www.dfat.gov.au

b) National Impacts on Crop Production.

Firstly I would like to acknowledge and thank Dr Mark Howden and the Australian Green House Office for providing me with the information that has subsequently formed the basis for this chapter.

In the working paper 99/14 (Howden, et al., 1999), nine sites were selected across the existing wheat belt to conduct the studies to find out the effects that the increasing levels of carbon dioxide and temperature would have on Australian wheat production. Another trial site was selected at Burenda that is situated in the Mitchell grasslands of south western Queensland (near Charleville). While this area is currently out side the wheat belt, and is considered too marginal for wheat it may become viable under feasible changes of CO2 and climate. When this report was conducted there had been no other studies conducted into the effects that global climate change would have on wheat production in Australia.

In their experiments it was found that by simulating the doubling of the CO2 levels to a level of 700 ppm alone increased wheat yield with in the current wheat belt by 5 to 43% when compared to the simulated 100 year average. At the Burenda site the yields increased from 0.85 t/ha to 1.3 t/ha this represented an increase of 50%. The relative increase was least at sites where evaporative demand and hence soil moisture stress was least and tended to be greater at drier and warmer sites as found in controlled experiments. When this increase in yield caused by the doubling of CO2 was calculated over the national cropping areas the national average yield increase was 24% i.e., 3.4 MT. The greatest increase was in Queensland at 39% and the least in NSW and Victoria at 18% (Howden, et al., 1999).

As I have discussed in the early stages of chapter 9 there are many measures we could take to mitigate the impact of climate change. The papers numbered 99/14 and 99/04 (Howden, et al., 1999), explain that the adoption of earlier sowing dates of wheat across Australia is a major way of mitigating the effects of climate change. This change in sowing date is made possible by the increase in temperatures that climate change would bring and this would therefore lead to a reduction in the annual frost risk period of a crop. This "adaptation" to climate change led to simulated increases in yield ranging from 14% in South Australia to 33% in Queensland and Western Australia (Howden, et al., 1999).

c) Future Profitability Of Australian Grain Growers.

In nearly all these trial results the grain protein was found to fall in the margin of 4 to 14 %. To maintain the current levels of grain protein the use of fertiliser would have to increase by up to 220 kg/ha (Howden, et al., 1999).This reduction in grain protein would lead to significant reductions in the prices that producers would receive per tonne of grain. Using the AWB Limited's ASW price matrix issued on the 19/2/01 wheat at 10% protein and 5% screenings delivered to Newcastle, was valued at A$ 184.80 (GST inclusive, as at 26/2/01). If the protein was to drop to a level of 8% and its other characteristics were to remain the same, the Newcastle price would be reduced by A$25.41 to A$159.39 (GST inclusive). I believe that reduction in the national protein level would not only have a huge impact on the profitability of growing grain but it could also have a large impact on our market share in the international market place.

In my opinion, the main way international markets would be affected is by other countries, (namely the US and those in the European Union), being able to produce grain at a higher protein level than Australia can. I believe that the wheat grown in these countries will also be affected by climate change, resulting in a similar reduction in grain protein. However, due to subsidies, their farmers will be able to increase their use of fertiliser, (to overcome low protein), and therefore produce the higher protein grain to fill these markets. In countries with subsidy systems, producers will be sheltered from the increases in input costs, the increase in production risks as a result of climate change, and therefore the true risks of production will be hidden from the markets. Obviously in a world without subsidies the amount of high protein grain being produced would fall and the price would subsequently increase. Thus we here in Australia would then be able to use more fertiliser to remain competitive in the market place.

12. HOW DOES AGRICULTURE SURVIVE WITH CLIMATE CHANGE.

a) Energy Index.

I believe that increased energy costs will have a profound effect on where and how grain is produced. In the future we will need to look at the inputs that go into the production of agricultural produce in a completely new way. A way to measure whether crops are grown in a manner that is energy efficient, and therefore grown in a way that reduces greenhouse gas emissions, could be the use of an "energy index". I am not suggesting that the index should be used to tax producers for their emissions, rather it could be used as a tool by producers to measure the level of their energy efficiency. Farmers would then have a way of bench marking themselves against others. While it could be said that measuring energy efficiency will occur by accessing net profitability of a farming system, I believe it would make the energy usage of a farming system more traceable. I propose that the energy index should be used in a similar way to the already existing harvest index. The difference is, that instead of measuring the ratio of grain to biomass that is produced, the Energy Index would be a measure of the amount of greenhouse gas emissions emitted per tonne of grain produced.

The Energy Index could then easily be transferred to the livestock sector for example the ratio of meat or fibre produced per unit of greenhouse emission. In the future if the Energy Index idea was accepted we may well be able to use it as a tool to help us enter the US or European livestock markets. After spending so much time in Europe last year I believe that the Europeans (particularly the western European countries) would be very receptive to a label that said that the beef was produced with a low energy index and was therefore, "greenhouse friendly". The reason that I believe that Australia could fill this newly created niche market, is the fact that most of the Australian beef is grass fed beef, unlike the U.S where most beef is produced in feedlots. Cattle that are fed on an intensive feedlot diet emit higher levels of methane than cattle that are grass-fed. In this situation the emissions that were released to produce the energy that goes into feedlot operations also has to be taken into account. I believe that this idea could be put to nearly every commodity produced. It certainly would be interesting to do the figures comparing a wool or a cotton energy index with indices from polyester and acrylic.

b) Technology.

There are several ways that will help sustain farm profitability and help us as a society survive within our changing climate whilst minimising its effects.

i) Genetically Modified Organisms

Genetic engineering has the potential to help farmers to mitigate the effects of climate change. Instead of associating GMOs with food production I believe that we should look at the huge environmental benefits they could provide. For example if crops were genetically modified so they were leguminous, and could fix even some of their own nitrogen, then we would be able to reduce our use of fertiliser. Not to mention the other flow on benefits this would have on the environment, such as reducing the nitrate run off from agricultural lands and reducing the amount of energy agriculture uses. Another avenue for plant modification could be to increase their ability to sequester carbon from the atmosphere. This would help see a rapid increase in the amount of carbon that could be sequestered in the immediate future. This would be of huge benefit considering the lag time between the time of emission of carbon dioxide to the time it reaches the troposphere.

GMO's also have a role to play in the production of alternative, renewable fuel. At the moment extraction of ethanol requires relatively large amounts of energy, for example every barrel of oil invested to extract oil there is a current return in the vicinity of 30 barrels. However, when ethanol is extracted, the rates of extraction are down to about 8 barrels of ethanol for every one barrel of oil invested as energy to extract it. So it is currently more efficient to use our diminishing oil reserves, (it is forecast by some that our oil supplies will be depleted by the year 2050) to continue the extraction of more oil than to make ethanol, or is it?

However, if we could increase the efficiency of ethanol extraction it could become a viable alternative to fossil fuels. I see this as one of GMO's most important roles in the future.

I believe that if the consumers who are currently opposed to GMOs could see a valid reason to produce them they would be at least interested in looking at what GMOs had to offer. At the moment the main place that GMOs have been targeted for is in the human food chain. The problem as I see it is that the people who have the money to pay for the technology of GMOs don't have a need for them. They are eating three meals a day and there is no shortage of food in their world. Why do we need a lettuce that tastes like lobster? Consumers don't want GMOs, especially if they think there is a risk that they could become a potential threat to the natural environment. Currently at the moment consumers, particularly those in Europe, don't think that the need justifies the end when it comes to GMO's.

Surely, one could assume, there would be a positive response if the public were told that a GMO crop's by-products could be used to make ethanol and then used in their cars to reduce carbon emissions. I believe that consumers around the globe would then see some real benefits of "risking" GMO's in the environment because there risks would justify the end.

In addition to the extraction inefficiencies of ethanol there is another perceived problem with using ethanol as an alternative fuel source, that is carbon still emits carbon dioxide when it is burnt. The ratio of carbon dioxide emitted per kilo joule of energy produced is similar between Super petrol (whose major component is octane) and ethanol. Super petrol produces 34200 kj/l (kilo joules of energy) at 25 degrees Celsius, and ethanol at 25 degrees Celsius produces 23418 kj/l. However, the emissions of carbon per kilo joule of energy produced is virtually the same, 0.0646 grams of CO_2 for ethanol and 0.0643 grams per kilo joule of energy produced for octane.

Even though the emissions of carbon are similar between petrol and ethanol, there is a big difference in the origin of the carbon that is emitted. The carbon that is emitted when fossil fuels are burnt comes from the non labile carbon pool. This means that the carbon that is released into the atmosphere when a fossil fuel is burnt was originally absorbed from the atmosphere thousands if not millions of years ago. So when it is released into today's atmosphere it is adding to the current pool of carbon in our atmosphere, (i.e. the labile carbon pool), thereby increasing the total amount of carbon in the atmosphere. This is why we are seeing the current levels of carbon in the atmosphere increasing.

By contrast when burning fuels such as ethanol, the carbon released into the atmosphere comes from the current labile carbon cycle, therefore not contributing to the levels of carbon currently in the atmosphere. This is because the carbon that is being released was only absorbed for the atmosphere in a recent time, say within an annual crop's life cycle. As a result the release of carbon from ethanol does not have an inflammatory effect on the amount of carbon in the labile pool. Maybe in the future the Bio mass used to make ethanol may not only be efficient to extract but could be developed to emit less carbon as well. This would be a good topic for a future Nuffield Scholar!

No doubt there are many other ways that we could use GMO technology to give us the efficiencies that we need to produce other bio products. Another example that comes to mind is the work that is already been done with corn starch and its use in the manufacturing of light weight concrete. I think that such possible environmental benefits are the most important areas for biotech research.

I believe that if the G.M.O debate was turned around so that G.M.Os were seen as a viable way for us to reduce our greenhouse gas emissions, thus helping to alleviate the green house effect, we could see a huge benefit to our society. Then these benefits may out weigh any potential risk to the environment that the use of GMO's may present, thereby leading to a change in the public's perception of GMO's.

In this future society a crucial step for humans will have been made. That is the step from a society that uses non-renewable energy sources, and one where farmers are seen only as food and fibre producers, to a new society of bio and reusable energy that is produced by farmers. In this new society we as farmers would then be seen as food, fibre and *fuel* producers.

ii) Global Positioning Satellites and Variable Rate Technology.

The adoption of variable rate technology (VRT) could already be considered to be a part of "best practice". VRT is also referred to as site specific farming where a paddock or strip of land is broken down to a grid square system and the inputs can be varied so each individual grid can be managed according to its individual needs.

The size of each grid varies from one farm to another depending on the variability found in that particular paddock or the width of the farmer's seeding equipment. When the paddock is harvested the yield is mapped using Global Positioning Satellites (GPS). Then each grid square is colour coded according to its actual yield.

While the crop is growing, it can be monitored by remote sensing from space to ascertain the crop's health and plant population etcetera. Once the crop is harvested the yields of each grid can be overlaid with the information from the remote sensing data and then further combined with the visual characteristics of the crop. Armed with this information farmers can then manage the inputs to their system in a more accurate manner. Instead of fertilizing a paddock according to the needs of the "average" soil in the paddock, the fertiliser can be managed to the needs of each half hectare, or smaller if needs be.

The increasing price of energy and the impact this will have on agricultural inputs combined with the increasing affordability of this technology, will I believe assist farmers to reduce their consumption of energy and therefore maintain, if not improve, their future profitability.

c) Carbon Sequestration.

i) What is carbon sequestration?

During photosynthesis in plants, carbon dioxide is removed from the air by the plant. The carbon dioxide molecule is then split and this causes oxygen to be released into the air. This is shown in the following reaction:

$$6CO_2 \quad + \quad 6H_2O \; = \; C_6H_{12}O_6 \; + \; 6O_2$$

(Carbon Dioxide and Water = Glucose and Oxygen)

The carbon remains in the plant to build organic compounds such as complex carbohydrates, cellulose, proteins and oils. The carbon stays in these compounds until it is released by burning the plant or by cultivation. For crops a portion of the carbon is removed in the grain or hay. If the crop's residue is allowed to rot back into the soil the carbon then becomes a part of the soils organic matter and is therefore taken out of the atmosphere and "locked" into the soil where it doesn't contribute to the greenhouse affect. This is why the practice of zero till farming is conducive to increasing the organic levels in soils and why cultivation releases the soil stored carbon back into the atmosphere.

ii) Carbon Sequestration and Agricultural Soils.

Minimum tillage in Australia in 1990 sequestered 5.9 million tonnes of carbon dioxide and it was forecast that in the year 2000 this figure could be as high as 6.3 million tonnes (Hassall and Asscoiates, 1997). Further evidence that carbon is released from soils when they are cultivated is the fact that the yields of biomass and grain of corn and soyabeans in the US have been rising, but there has been a decline in the levels of soil carbon. This is as a result of cultivation. It is also thought that the reason crops look better after inter row cultivation is due to the release of carbon and the effect of carbon fertilisation and not the traditional view that it made the roots search deeper for moisture.

The sequestration of carbon from agricultural soils is therefore another method being discussed to reduce carbon levels in the atmosphere. Although this tool could help reduce carbon levels I don't think it will play a significant role in adaptation to climate change. As I see it there are several problems with this scheme. At the Carbon Conference in Des Moines, Iowa we were told that the cost of implementing and administrating such a scheme could soon see any potential income eroded. For example, in the U.S it was found that in a 10 square metre plot the carbon levels varied by 16 tonnes per ha. Therefore, by the time the levels of carbon are measured to get a starting point and then re-measured to find the ending point I think that any financial benefits would soon be negated by the administration costs.

The other major problem with this concept is, how long will the carbon remain in the soil before it is naturally released into the atmosphere by soil respiration? The sequestration of carbon into the soil is seen by a lot of farmers as the lining in the cloud of climate change. The issue that farmers are not told about is, what happens if you don't actually sequester any carbon in your soil and you actually lose carbon from your soil? This loss would more than likely occur through the practices used on your farm, the best example being the losses of carbon through tillage. Every time that soil is disturbed there is a release of organic carbon into the atmosphere. The amount that is emitted varies according to a large number of factors that range from; the time of the day and the time of year that cultivation takes place, soil temperature and soil health. When this carbon is released, would the farmer have to pay back the money that he or she has been paid for sequestering carbon as they are now re-releasing it back into the atmosphere?

iii) Carbon Sequestration and Natural Carbon Sinks.

The sequestration of carbon in forests and oceans falls into the same bracket as agricultural soils when it comes to people being paid to sequester carbon in them. There is probably an even bigger question over the ocean's and forest's ability to hold carbon without it becoming a carbon source in the future.

S. George Philander in his book "Is The Temperature Rising? ", makes the point that the deep waters of the oceans are rich in carbon dioxide because they are cold and if the temperature of the water increased it would see the release of this carbon into the atmosphere. He continues to say that the thermohaline circulation of the ocean involves the sinking of dense, saline water in the northern Atlantic Ocean, and if the temperature rises significantly in this region, the associated increase in rainfall would see a reduction in salinity of the surface water. This could make those surface waters so buoyant that they no longer sink. In this case the thermohaline circulation would be altered and the consequences could include the interruption of the ocean's ability to act as a sink, and lead it to become a source of carbon resulting in an acceleration of global warming.

The ability of vegetation to hold carbon for a significant period of time has also been questioned by The Hadley Centre in the Meteorology Office in the U.K. The following information and predictions were published in a paper titled "Acceleration of Global Warming due to Carbon Cycle Feedback in a Coupled Climate Model" (Cox et al., 2000). This paper was accepted for publication in the "Nature" magazine where the results of their new climate model were first announced in its November 2000 edition. The Hadley Centre's new model called, "HadCM3" was first coupled to an ocean carbon cycle model, "HadOCC" and then it was coupled to a dynamic global vegetation model "TRIFFID". The TRIFFID models the state of the biosphere in terms of the soil carbon, and the structure and coverage of five functional types of plants within each model grid box (broadleaf tree, needle leaf tree, C3 grass, C4 grass and shrub).

This new climate model has shown that a rise in CO2 alone tends to increase the rate of photosynthesis and thus terrestrial carbon storage sinks, providing other resources are not limiting. However, plant maintenance and soil respiration rate both increase with temperature. As a consequence, climate warming (the indirect effect of a CO2 increase) tends to reduce terrestrial carbon storage, particularly in the warmer regions where an increase in temperature is not beneficial for photosynthesis. At low CO2 concentrations the direct effect of CO2 dominates, and both vegetation and soil carbon increase with atmospheric CO2. However, as CO2 in the atmosphere continues to rise, terrestrial carbon begins to decrease, since the direct effect of CO2 on photosynthesis saturates the plant, the specific soil respiration rate continues to increase with temperature. Thus once the plant is saturated with CO2 it begins to re- release CO2, the transition between these two regimes occurs abruptly at around the year 2050 in the experiment. The land carbon storage decreases by about 179 GtC (gigatonnes of Carbon) from 2000 to 2100, accelerating the rate of CO2 increase over this period (Cox et al., 2000).

The idea of storing carbon in "sinks" (which absorb carbon from the atmosphere) is a very sound one. It is very important that the use of sinks is promoted because it is a good way to help reduce the amount of carbon in the atmosphere at the moment and keeping it inert for the short term. However, the concept of earning financial rewards for storing carbon, (i.e. Carbon credits), is suspect because there is no guarantee as to how long the carbon will remain in the sink.

13. CONCLUSION.

Writing this report has been enjoyable for me. I have relived my Nuffield experience and renewed a lot of acquaintances that I had made on my trip. I have also made new contacts in the field of climate change here in Australia. I would once again like to thank the Nuffield Farming Scholarship Trust and my sponsors the GRDC and QANTAS for giving me such an incredible experience.

There were times where this topic became too depressing for me and I began to wonder if there was going to be a tomorrow, not only for agriculture, but for life as we know it. However, such thoughts did not last for long and it was these thoughts that forced me to invoke a positive response to the issue. To become positive I had to generate solutions, these ideas on ways to mitigate the effects of climate change have been described in chapter 12.

Although I have included many scientific results in this report, it is still only a very limited collection. However, every attempt has been made to make it as factually accurate as possible while still maintaining the Nuffield ethos that the report is, "by a farmer for farmers". In saying this I hope much of the information in this report is also of interest to the wider public, who can then make up their own mind about whether climate change is happening or not, and then what we should do to implement the Kyoto Protocol.

Most importantly I hope readers, in particular farmers, will begin to think about the amount of energy they are using in their everyday life and in their work place. I believe many of the solutions mentioned in this report, regarding ways to improve the use of energy, should already be seen as best practise. However, with the increasing price of energy, it will become a necessity for every farmer to adopt the energy saving practices to remain in business.

I believe the opportunity to use GMOs in helping us mitigate the effects of climate change and to reduce our energy usage is one that should be pursued with the utmost urgency, as it may be the single most effect measure we could adopt. At the same time the adoption of this technology would also play a major role in helping farmers to remain viable and environmentally sustainable in the future.

The models used as a basis for research into climate change are continually being modified and updated. Any research into this topic may well have an academic life of only three to four years. A similar time frame applies to this report. I believe Australian research funds should continue to be directed towards the effects that climate change will have on our rural industries and society. We should investigate measures we can take to mitigate the impacts of climate change on agriculture, and then determine how agriculture can remain viable under the increasing cost structure induced by climate change.

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