Emerging Opportunities for Australian Agriculture?

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Abstract

Agriculture globally and in Australia is at a critical juncture in its history with the current changes to input costs, commodity prices, consumption patterns and food stocks. Constraints are emerging in terms of land and water resources as well as imperatives to reduce greenhouse gas emissions in the face of a carbon-constrained world. There is evidence that rates of increase in agricultural productivity are slowing, both in Australia and overseas. On top of all these drivers of change, agriculture is the sector probably most exposed to climate change, and Australian agriculture is as exposed as any in the world.

Against this turbulent background, we review the emerging opportunities (and threats) for Australian agriculture. We consider topical opportunities associated with new products or services from agriculture, namely biofuels, forest-based carbon storage in agricultural landscapes, bio-sequestration of carbon in agricultural soils, and environmental stewardship schemes that would reward farmers for nature conservation and related non-production services from farming land. While there are situations where all these emerging opportunities will have a place and will deliver benefits to both farmers and the wider community, our overall conclusion is that none of these, on their own, will transform the nature of Australian agriculture.

Instead, we argue that the greatest "emerging opportunity" for Australian agriculture is to achieve productivity breakthroughs in the face of current and emerging constraints. We have formed this view by looking through the lens of the global food production challenge which sees the need for a doubling of food production by 2050 in the face of increasingly constrained land and water resources, soil degradation, increasing energy scarcity and limits on greenhouse gas release to the atmosphere. These same land, water, soil, energy and atmospheric constraints to agriculture apply in Australia and will shape both farming and the agricultural R&D agenda over coming decades.

In the face of such national and global agronomic challenges, we conclude by highlighting the skills challenges facing agricultural science in Australia – the demand for the integrative skills of agronomy appears strong but the sector has suffered from disinvestment in recent decades.

Introduction

We "agronomists" live in interesting times. Can anyone remember a time when global agriculture has experienced such a rapid rate of change and was faced with so many imponderables, "wicked" problems and perhaps opportunities? The global food security situation has captured the attention of politicians and public alike. Equally importantly, agriculture has to quickly adapt to the fact that it is operating in a carbon-constrained world. The challenges (and opportunities) facing Australian agriculture in 2008 reflect both of these global drivers as well as forces more specific to Australia.

We are seeing unparalleled shifts in global food markets – in terms of changes in demand for protein foods, low levels of global food stocks, increasing food prices and social/political unrest in some regions arising from these developments. We are also witnessing very significant shifts in the markets for agricultural inputs. Energy costs have risen more than 3-fold, and fertiliser and agro-chemical costs have increased more than 2-fold. In parts of Australia, prices paid for irrigation water are 5 to 10 fold higher than historical levels. For the first time, we are seeing a major diversion of food into non-food markets associated with biofuel production in Europe, USA and Brazil. Moreover, there is an unprecedented demand (or prospects) for non-food production products or services from agricultural land – be it in carbon storage, fresh water yield, biodiversity conservation or some other land values associated with landscape amenity and human settlement. These developments are all occurring against a backdrop of massive environmental change, in both the climate and atmosphere as well as soil and landscape assets. Finally, in addition to this change, we may be starting to see a "plateau" develop in rates of increase in agricultural productivity.

Global Issues Paddock Action. Proceedings of the 14th Australian Agronomy Conference. September 2008, Adelaide South Australia.

In this paper we seek to look beyond these headlines to explore the emerging opportunities (and threats) for Australian agriculture.

Agriculture in context

A global perspective

Real food prices have shown declines from 1960 to 1990, apart from a short-lived perturbation associated with the 1974 oil crisis (Figure 1). The FAO food price index more than halved over this period, as uptake of agricultural technology and expansion of agricultural land exceeded rates of increase in food demand associated with population growth and economic development. These data are of course global averages and there were regions such as sub-Saharan Africa that missed out on this boom in agricultural productivity. From 1990 to 2005, real food prices were largely stable, however, over the last two years, we have seen a dramatic rise in food prices and they are now back at levels equivalent to those (in real terms) that applied in 1978. In two years, about half the downward adjustment in food prices achieved since 1960 has been re-instated.

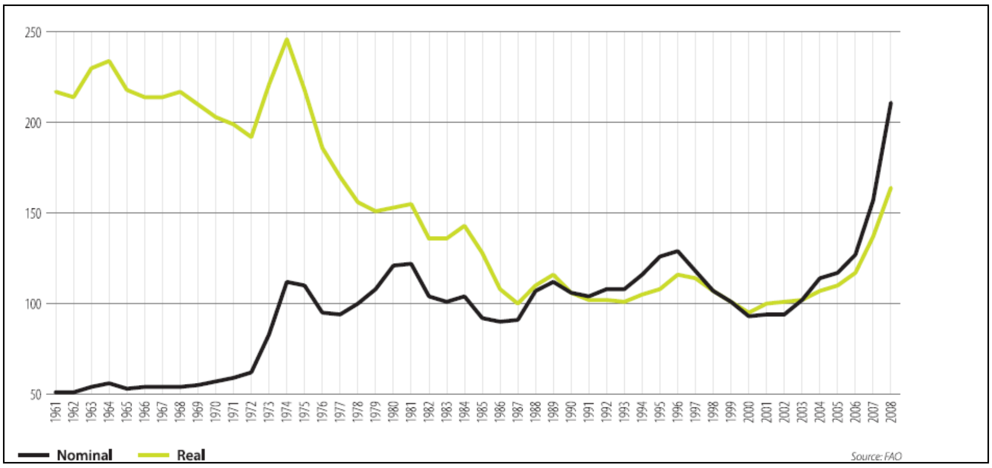

Figure 1. Extended annual FAO Food Price Index (1998-2000 =100) (FAO, 2008)

These dramatic changes in global food prices have been observed in all commodities, but have been most pronounced in oilseeds, rice and wheat (FAO, 2008). The drivers of these recent dramatic shifts in agricultural product prices are complex and are the subject of considerable recent commentary and analysis (FAO, 2008; Stoeckel, 2008). The general consensus appears to be that key drivers for rising global food prices include:

On the demand side,

- strong growth in demand associated with rising world population, but more importantly, rising living standards in some rapidly developing economies (such as China and India) linked to increasing per capita food demand and changing diet composition to include more grain-based livestock production; and
- diversion of food crops to non-food uses such as biofuels – in 2007 on a global basis this totaled 8.4% of coarse grains, 0.6% of wheat, 17.3% of sugar, 3.8% of sugar beet and 8.7% of vegetable oils (OECD, 2008a)

On the supply side,

- weak growth in production globally (areas planted and yields) relative to consumption;
- below average harvests associated with unfavourable seasonal conditions in major growing and exporting regions;
- net impacts of government interventions (trade restrictions, price controls suppressing production); and
- declining global food stocks.

An Australian perspective

Longer term trends in productivity and profitability in Australian agriculture provide an important context for any consideration of emerging opportunities. For effectively the last 30 years, which covers the working life of a great many current agronomists, we have been working under the paradigm of declining terms of trade for Australian farming (Figure 2).

Does the recent reversal in world food prices mean that we are entering a new "golden age" for Australian agriculture?

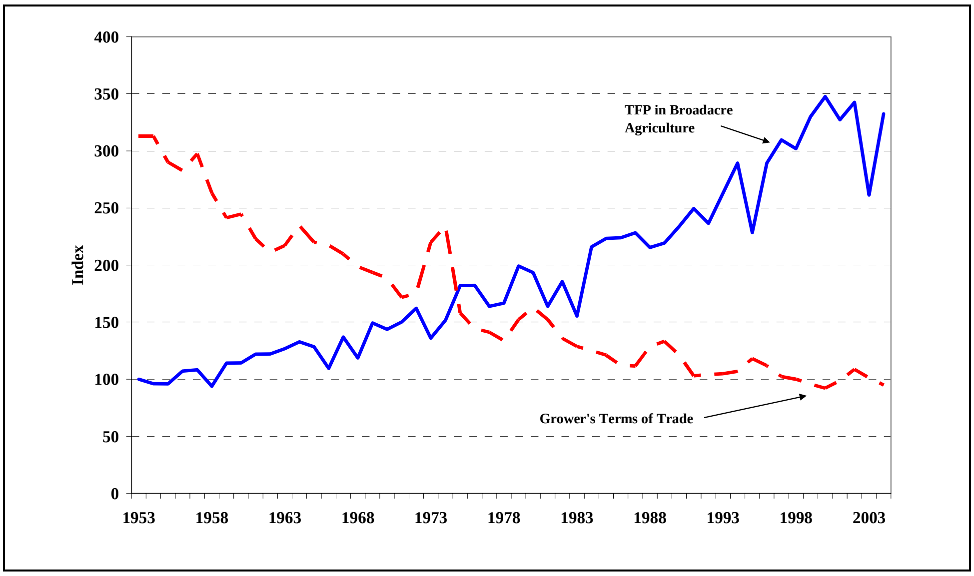

Figure 2. Trends in terms of trade (index of output prices/index of input costs) and total factor productivity (TFP) for Australian agriculture (1953-2003) (Mullen, 2007).

More recent data from ABARE (Figure 3) show a marginal improvement in farmer's terms of trade since 2004/05, although when looked at in the bigger picture (Figure 2) one might conclude terms of trade have been stationary since around 1990.

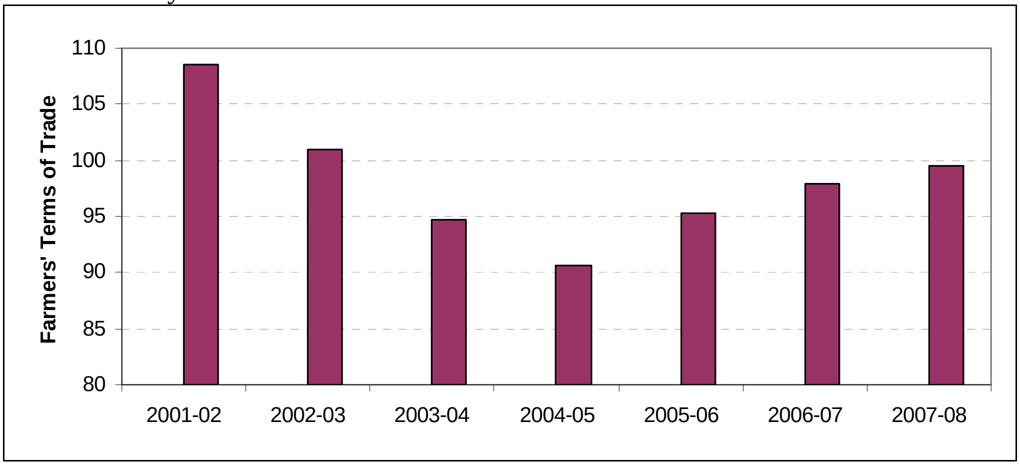

Figure 3. Australian farmers' terms of trade (ratio of index of output prices over index on input costs) since 2001-02. Note: 2006-07 and 2007-08 values are ABARE estimates and forecasts respectively. (Source: ABARE - Indexes of prices paid by farmers, and terms of trade: http://www.abare.gov.au/interactive/agsurf/).

ABARE commodity price forecasts would suggest that world food prices have probably peaked (ABARE 2008) and history would suggest that a "supply response" will kick in to limit further rises even if some of these demand-side drivers remain strong. Any supply response in Australian (or global) agricultural production is going to be dependent in the short term on favourable seasonal conditions in key production regions, in the medium term on access to new land and water resources and in the longer term on improvements in productivity. Generally speaking, these medium and long term opportunities appear to be far less abundant in 2010 than they were over the 1960 – 1990 period.

The importance of productivity gains

The story of Australian agriculture for at least the last half century has been one of declining returns for food production and increasing costs of many inputs. The so called "cost-price" squeeze has meant that annual productivity gains of 2% or more have been necessary to retain farm enterprise viability in the face of rising costs and declining real prices for agricultural commodities (Figure 2). The grain cropping industry has been most successful in achieving these productivity gains in the face of declining terms of trade (Figure 4).

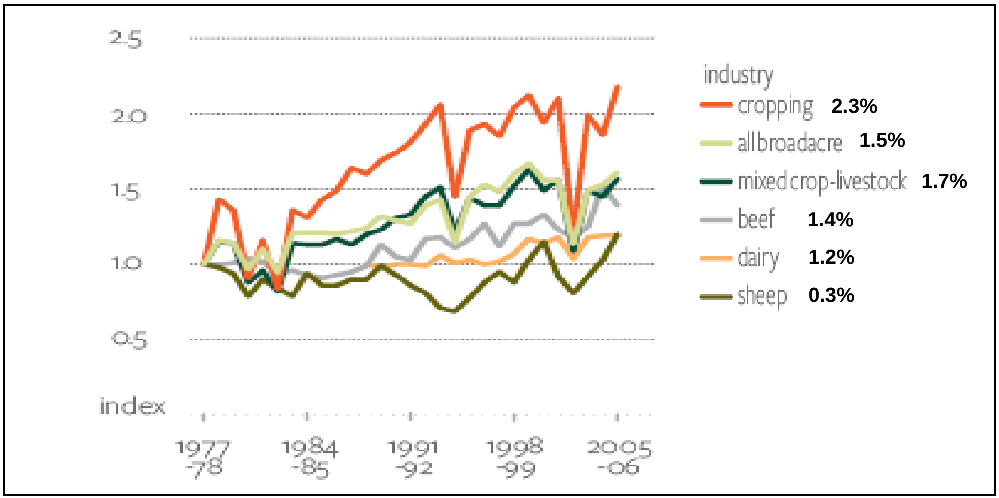

Figure 4. Trends in total factor productivity in different segments of the Australian farm sector (Source: www.abareconomics.com/interactive/08ac_march/htm/a3.htm).

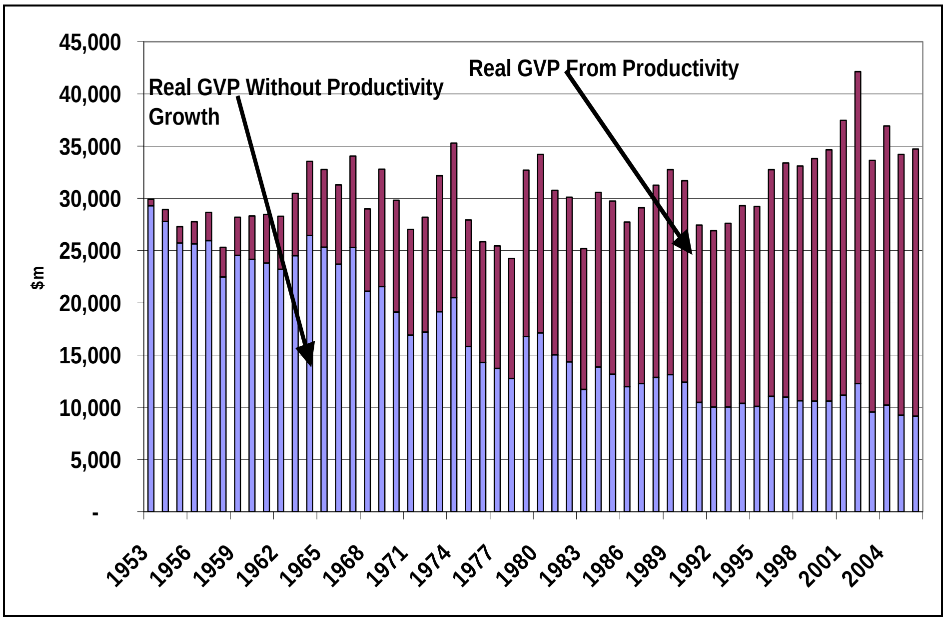

Figure 5. Value of productivity growth in Australian Agriculture (1953-2006) after Mullen (2007)

The significance of this productivity growth is illustrated in the diagram (Figure 5) prepared by NSW economist, John Mullen (2007). Mullen writes:

"Following Mullen (2002) and applying these assumptions, the gross value of agricultural production (GVP) in Australia in real terms grew slowly from just under A$30 billion pa in the early 1950s to about A$35 billion pa post 1997 (Figure 5). However, if agriculture had remained static and continued using 1953 levels of technology, real agricultural output may have only been about A$10 billion pa in 2004. Seventy per cent of the value of farm output in 2004 came from various sources of productivity growth, including improvements in infrastructure and communications, higher quality inputs, and new technologies developed and implemented as a result of agricultural research and extension activities."

For grains, these impressive productivity gains have been achieved via a combination of:

(a) technology development and adoption – both improved varieties and better farm management practices, in particular water, nutrient and soil management, (Angus, 2001), and
(b) structural adjustment in farm enterprises, in particular economies of scale through farm amalgamations (Kingwell and Pannell, 2005).

In terms of the former driver, historically two thirds of productivity growth has been estimated to come from improved farming practices and one third from better varieties (Bell et al., 1995, Constable, 2004). In terms of the latter driver, broadacre farm enterprise numbers in the Australian wheat-sheep zone have fallen from 46,767 to 35,305 over the 1990 to 2007 period (ABARE: http://www.abare.gov.au/interactive/agsurf). Over this same period, the average size of a broadacre farm in this same zone increased from 1,730 ha to 2,386 ha and the annual cropped area rose from 341 ha to 565 ha.

In summary, while Australian agricultural enterprises may currently be experiencing a window of enhanced opportunity with high soft commodity prices, they are also exposed to input costs that have risen at a rapid rate. Overall farmers' terms of trade have not changed much over the last 15 years and with the cost base now rising dramatically
, agriculture is very vulnerable to any significant deterioration in commodity prices. Hence the imperative for continuing productivity gains appears to be on-going. Given likely global supply responses to current high prices and continuing cost pressures in the basket of agricultural inputs that are linked to world energy prices, it would be unwise to conclude that the cost-price squeeze and the need for productivity gains has been consigned to history.

Productivity plateau?
There is increased reference to an emerging "productivity plateau" where the impressive annual productivity gains of the last 50 years are starting to slow. Internationally, there is some evidence in the data that the annual rate of yield increase is declining, from 2-3% p.a. in the 1960's to around 1% currently (Figure 6).

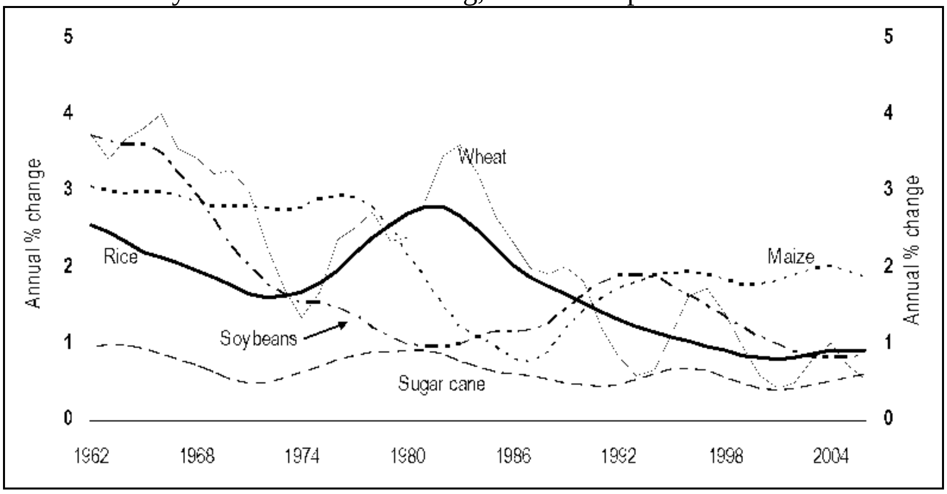

Figure 6. Global commodity yield increases (% annual change) (from Stoeckel, 2008)

In Australia, productivity in broadacre agriculture (measured as growth in agricultural output less the growth in inputs) rose by a factor of almost 3.5 over the 50 years from 1953 to 2004. (Figure 2). However, while this long term productivity growth has been impressive, there is some evidence that the rate of productivity gain is declining. Year to year variability in productivity growth is strongly associated with climate variability and hence these time series analyses of productivity gain are quite sensitive to the time periods chosen. Recent ABARE analyses for the broadacre cropping sector suggest rates of productivity growth over the last decade (1995 to 2006) have been less than one quarter of those achieved from 1977 to 1994 (Figure 7).

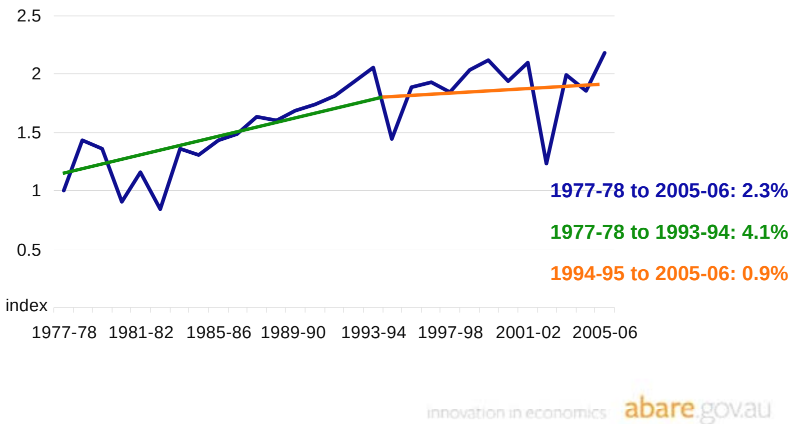

Figure 7. Total factor productivity growth in Australia's cropping industries (Source: ABARE)

The history of agriculture in Australia, apart from an initial phase of system rundown prior to 1900, is one of phases of productivity gains interspersed with "plateau periods" where progress slows (Figure 8). The largest single increase in average Australian wheat yields took place between 1990 and 2000 and while many factors will have contributed, the three fold increase in nitrogen fertiliser usage over that period (Figure 9) is likely to have been a very significant driver. The question now emerges as to what will drive the yield gains and/or productivity improvements over the 2000 – 2020 period?

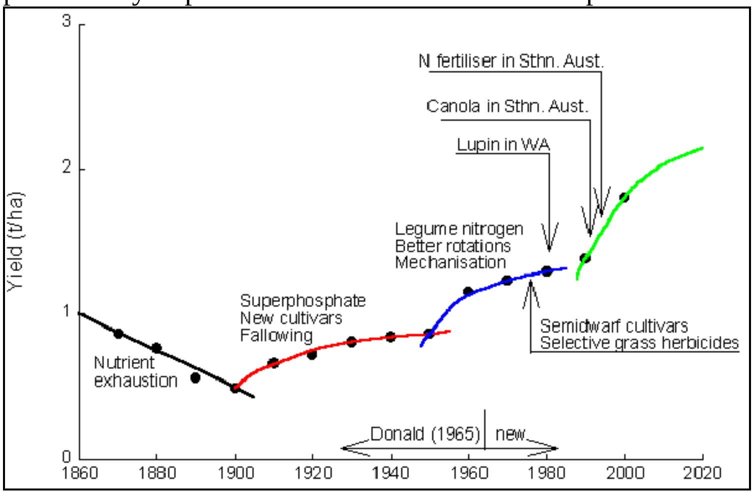

Figure 8. Average Australian wheat yields (interpreted by Donald (1965) and Angus (2001)

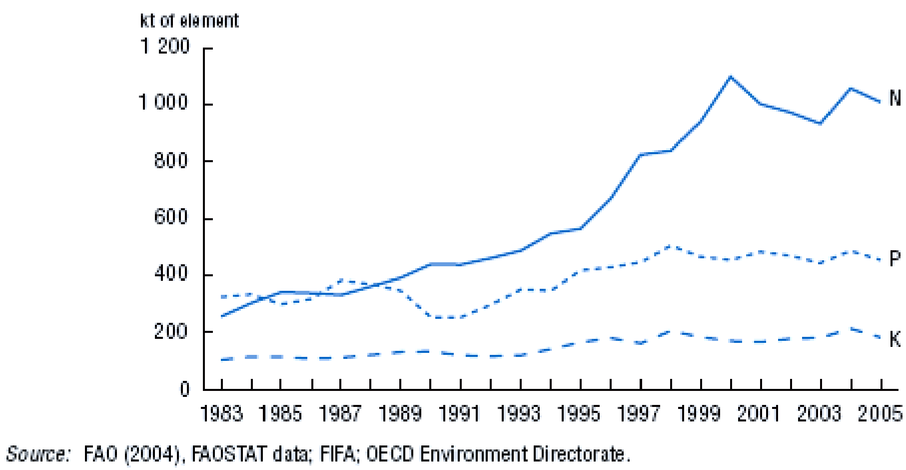

Figure 9. Fertiliser sales in Australia, 1983 – 2005 (from OECD 2008b)

Evidence of a narrowing yield gap
Davidson (1962) famously determined that yields attained on experimental stations are generally much higher than commercial farm yields. He found that the mean weighted farm yields reached only 60% of experimental yields for wheat in Australia. This disparity is often referred to as a 'yield gap' between attainable yields and farmer yields. Along with improving the genetic and realised yield potential of crop varieties, significant research effort is aimed at closing the yield gap as the basis for the increases in cropping productivity observed over past decades (Dobermann and Cassman, 2002).

Carberry (2007) collated information on APSIM (Keating et al., 2003) performance in simulating the yields of over 600 commercial crops of barley, canola, chickpea, cotton, maize, mungbean, sorghum, sugarcane and wheat monitored over the period 1992 to 2007 in all cropping regions of Australia. The results indicated that APSIM can predict the performance of commercial crops at a level close to that reported for its performance against experimental yields. This agreement between commercial crop yields and yields simulated by APSIM suggests two contrasting realities for Australian agriculture. The upside is that top end Australian farmers, as represented by those sampled in that study, are achieving the commercial yields they should be achieving given the environmental and agronomic management constraints imposed on crops – the yield gap has disappeared for these better farmers. It appears that, on the whole, most crops are little affected by yield reducing factors such as weeds, pests and diseases or poor agronomic management which may not allow crops to meet their potential. If such factors were influential then the APSIM model, which doesn't explicitly account for biotic stresses nor poor operational management, would significantly over-predict crop yields. In fact, the analysis of Carberry (2007) suggested that the supply of water and nitrogen (parameters well dealt with by APSIM) can account for most of the variation in crop yields and farmers are mostly controlling other yield-limiting factors such as weeds and diseases. Additionally, the economic realities of the cost-price squeeze on the relatively unsubsidised Australian agriculture are likely incentives to ensure real efficiencies in operational management (Kingwell and Pannell, 2005).

The downside reality to this interpretation is that the exploitable yield gap, and thus potential for further yield improvement by Australian farmers, is soberingly small. The survey of APSIM-simulated commercial crops suggests most achieved their potential for the variety, sowing date, fertiliser inputs and agronomy as practised. Undoubtedly, some of these crops could have been sown at other times and with higher inputs which may have achieved higher yields in the season experienced. However, there currently exist few technologies for farmers to forecast seasonal outcomes at the time when decisions on crop inputs are made. Therefore, if many farmers are achieving their expected yields, their opportunity to increase productivity simply by managing their crops better becomes limited. Huang et al. (2002) also suggest that the exploitable yield gap between farm and experimental yields has narrowed worldwide.

One element of uncertainty with regard to the generality of the above conclusion is that the crops modelled by Carberry (2007) managed by the better farmers around Australia. However, the sample size is relatively large, and covers a wide range of crops and achieved yields. At a minimum, it demonstrates that the conclusion is relevant to those farmers who lead in farming practices in Australia.

Emerging Opportunities
The foregoing analysis establishes something of a "baseline" for any discussion of future directions for Australian agriculture. Issues of input costs, commodity prices, terms of trade and productivity growth are not new – they have been fundamental to the business of farming and the focus for agricultural research for 50 years or more. In what follows, we examine some more contemporary "opportunities and threats", but we do this in the context of the longer term trends in productivity and profitability described above.

Biofuels
While there has been a furious "fuel versus fuel" debate ranging for over 12 months in the international press, the diversion of Australian food production to biofuels is occurring at very low levels. Recent estimates indicate Australia produced 84ML of ethanol and 76ML of biodiesel in 2006/07 – with the bulk of the former coming from C Molasses (a by-product of sugar milling) and waste starch byproducts and the bulk of the latter coming from waste cooking oil and tallow (Batten and O'Connell, 2007). Hence, unlike in the US and EU, where respectively 38% of maize production is estimated to go to ethanol and 80% of oilseed production to biodiesel (OECD 2007), it appears that very little Australia grain and oilseed production is currently being diverted from the food chain to the fuel chain.

There are significant numbers of proposed ethanol plants in Australia (O'Connell et al., 2007), but progress to construction and start-up of operations has been slow. Nevertheless, a grain based ethanol plant (capacity 80ML p.a., 200,000 tonnes sorghum) is nearing completion at Dalby in QLD and a second grain-based ethanol plant (capacity 160ML p.a., 400,000 tonnes of low protein wheat) is expected to be operational by the end of 2009 at Kwinana in WA. Why the big difference between Australia and the US and what does it say about the prospects for biofuel production in Australia?

O'Connell et al., (2007) have reviewed the prospects for biofuel production in Australia. Conversion of all Australia's grain and sugar crops could produce 14.8 GL of ethanol (average of 2000 to 2005 crop yields). This would represent 50% of Australia's petrol usage in 2004/05 (when adjusted for differences in energy content of ethanol and petrol). Clearly that is not going to happen as there would be massive dislocation to food and feed value chains, and price pressures on ethanol feedstocks would limit the economic viability of such operations. Taking only the exported fraction of current grain and sugar crops, Australia could produce 9.7GL of ethanol (32% of petrol usage). This situation could happen if the grain or sugar was worth more as a biofuel feedstock than as an export commodity and sufficient infrastructure was built to process the feedstock. However, the uncertainties are high, with biofuel profitability being fundamentally sensitive to feedstock prices and international oil prices. The tax treatment of ethanol introduces a third significant source of uncertainty while seasonal weather-related volatility in feedstock production provides a fourth over-riding source of business risk. These uncertainties and risks are the major reason for the relatively slow development of biofuel infrastructure in Australia, in contrast to the US where government intervention has underpinned investment decisions.

Analysis of the relationship between sugar, grain and oil prices can illustrate the uncertainties in determining the "breakeven oil price" for different feedstock prices to ethanol plants. Under the oil price at the time of writing (July 2008, US$145/bbl) and grain price (US$320/tonne), grain-based ethanol would be marginally profitable without an excise exemption or significantly profitable with this exemption. This is quite a different situation to that which existed in Australia in 2003 when CSIRO, ABARE and BTRE evaluated Australia's 350ML biofuel target (CSIRO, 2003). At that time, with an oil price of US$25/bbl and grain price of A$137/tonne, grain based ethanol was some way off commercial viability. Similarly, for sugar-based ethanol, at the current export sugar price (around $300 / tonne) and exchange rate (0.90 US$: A$), a litre of ethanol could be produced for A$0.82/litre compared to a litre of petrol for A$1.01 (both figures net of excise, GST and all distribution and retailing costs and profit margins). Under such conditions, it would certainly pay to put the entire Australian sugar crop (not just some fraction of the C Molasses by-product) into ethanol and the current 38.1 cents/litre excise exemption would also drop to the profit bottom line. That would generate perhaps 2800 ML of ethanol which is enough to produce an E15 blend nationally. However, approximately $2B of infrastructure investment would be required and volatility in sugar and oil prices on world markets creates a very unstable base upon which to build such a massive infrastructure investment.

In summary, we see significant hurdles to large scale diversion of food crop production to biofuel production in the near future in Australia. This view is reinforced by the realisation that benefits in terms of greenhouse gas abatement from grain-based ethanol (in the order of 20% greenhouse gas saving on a full life cycle basis) or C-molasses based ethanol (up to 50% savings), are not sufficient to be a fundamental driver for long term conversion of food crops to biofuels (O'Connell et al., 2007).

Increasingly the research and development focus in biofuels is shifting to second generation processing based on ligno-cellulose feedstocks. Such processes have the advantages of being more independent of the food and feed value chains, hence a more stable feedstock price, and they are expected to deliver significantly more attractive greenhouse gas abatement rates (in the order of 80-90% reductions compared to petrol). Data summarised by Lange (2007) suggests that ligno-cellulose based ethanol technologies start to become economically competitive at oil prices in excess of US$100/bbl., although considerable uncertainties remain in terms of feedstock and processing costs. The US Dept of Energy is currently supporting the development of six commercial scale ligno-cellulosic ethanol plants in the US (Ahring, 2007). However, significant technical and sustainability challenges remain before second generation biofuels become commercially viable, especially given issues around the soil and water management of large-scale harvesting of biomass from agricultural lands.

Farming carbon
Few issues have captured the imagination and interest of segments of the farming community in recent years like the notion that there is an untapped income source lying in wait in the form of “carbon credits’. In fact, this is a hugely complex issue subject to considerable uncertainty as Australia designs cost-effective market mechanisms to reduce the “greenhouse emissions” intensity of our economy. This “opportunity” has to be approached from two perspectives, namely greenhouse emissions as a liability and carbon offsets as an opportunity. While there is much we don’t know about the likely impact of greenhouse gas mitigation on the agricultural (and forestry) sector(s), there are some fundamentals that are worth exploring.

In 2006, agricultural emissions under the Kyoto accounting rules made up 15.6% (87.9 Mt CO2-e) of the national greenhouse emissions inventory. These agricultural emissions are dominated by methane, principally from livestock (76.4% of agricultural emissions), and nitrous oxide losses (23.6%) from fertiliser use and, to a lesser degree, savannah burning and manure management (Figure 10). Recent reductions in land clearing have meant that the land use, land use change and forestry components of the national greenhouse emissions inventory has reduced to 6.9% of national emissions in 2006. This term represents the net balance of deforestation and reforestation (Figure 11) and essentially enabled Australia to balance its increased emissions from the industrial and fugitive energy sectors and meet Kyoto targets over the 1990 – 2010 period.

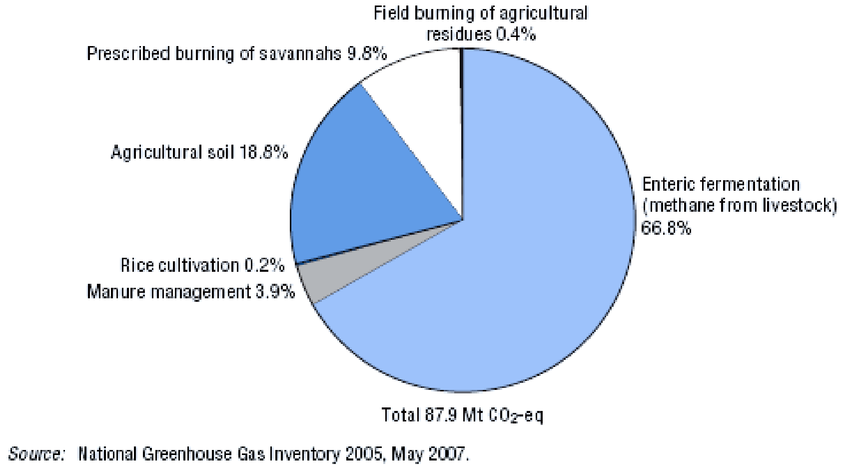

Figure 10. Greenhouse gas emissions from agriculture (2005 estimates).

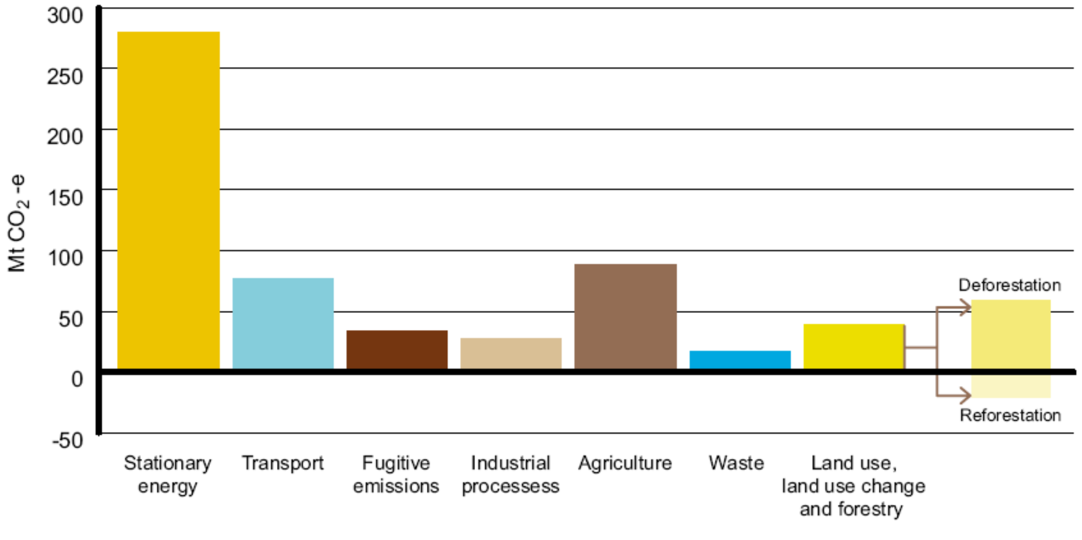

Figure 11. Australia’s national greenhouse gas inventory, 2006.

There is considerable uncertainty with regard to the impacts of a “price on carbon” on Australian agriculture. Agriculture’s exposure is not just associated with its own direct emissions, but also with the emissions embodied in energy used in farming activities. To get a sense of perspective on the scale of the greenhouse mitigation challenge for Australian agriculture, 87.9Mt of CO_2-e, costed at $40/t, represents a cost burden of $3.5B. This compares with an average total value of agricultural output of $37.3B in 2005-07 (ABS data). If this full $3.5B cost was to be absorbed by the agricultural sector, it would represent a significant fraction of the profit term for Australian agriculture. For instance, while a little dated now, the NLWRA estimated profit at full equity was in the order of $7B on average over the five year period up to 1996/97 (NLWRA, 2001).

The recently released Green Paper on a “Carbon Pollution Reduction Scheme” (Australian Government, 2008) continues to support the overall intent for greenhouse mitigation policy responses to be as broadly based as possible. However, in practical terms the Green Paper is proposing that:

- Forestry operations that are Kyoto compliant should be able to “opt-in” to an emissions trading scheme. This is likely to provide positive support for forestry plantings, some of which will take place on agricultural land.
- Inclusion of agriculture in any carbon emissions reduction scheme is not seen as practical initially, although the Government’s “inclination” to include agriculture remains, but not before 2015 with a final decision scheduled for 2013.
- Importantly, the Government is not proposing to establish an offset scheme for the agriculture sector prior to this final decision being made in 2013.

While potential liabilities clearly lie ahead for Australian agriculture in terms of accountability for its own direct emissions and higher input costs associated with energy and energy-dependent inputs, opportunities may lie in the storage of carbon in agricultural landscapes. While any such “offsetting” opportunities are likely off the agenda until at least 2015, they are still likely to generate intense interest in the farming community over coming years. The two major offsetting opportunities generating interest are forestry-related operations or soil carbon-related sinks.

Forest-based sinks

The forest-based carbon sinks, representing tree growth on previously cleared (Kyoto-compliant) land, is a real opportunity as they currently are measurable in terms of above ground sinks. A major question concerns the treatment of long-lived carbon sinks in harvested timber products, particularly with regard to whether they are assessed as part of the carbon storage benefit. There is more controversy over the wider systems implications of expanded forest based carbon sinks on other industries . These include the displacement of food production on agricultural land, the implications for water flows in catchments and downstream industries and full lifecycle implications for greenhouse emissions when all these factors are considered together.

Polglase et al. (in press) examined agroforestry potential across the Australian land surface using data on soils and climate, forestry knowledge of the adapted tree species and their economic competitiveness with existing agricultural land use. Excluded were areas where additional water interception by the forest was > 150 mm yr^{-1}. With these criteria, a total of 9.1 million ha were identified (Figure 12) with a combined value of $1.9 billion yr^{-1} (assuming a carbon payment of $20 t^{-1} CO_2-e). The annual rate of carbon sequestration was predicted to be 39 million t C yr^{-1} at an average areal rate of 4.3 t C ha^{-1} yr^{-1}, equivalent to about 25% of Australia’s net 2005 greenhouse gas emissions. Notwithstanding limitations in economic assumptions and unconsidered issues such as salinity, this study suggests that there are large areas of Australia potentially available for establishment of new agroforestry enterprises for commercial and environmental benefit.

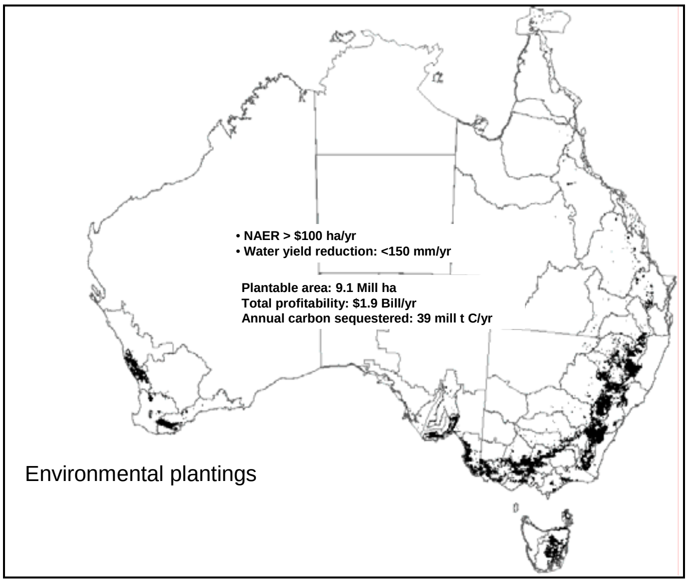

Figure 12. Areas identified as potentially suitable for agroforestry planting in which carbon sequestration (valued at \$20 t^{-1} $CO_{2\text{-}e}$) was competitive with current agricultural returns (>A\$100/ha/yr than current agricultural profit at full equity) and water yield reduction was < 150mm/yr.) (Source Polglase et al., in press)

Soil carbon sinks

The interest in soil carbon as a source and sink of atmospheric CO_2 is understandable. The carbon pool in the world's soils is three times that in the atmosphere (IPCC, 2001). Hence, any change in the belowground pools resulting from changes in land-use (conversion to crop or pasture, afforestation), can have major impacts on carbon concentrations in the atmosphere (Manlay et. al., 2007). However, the issue of soil carbon sinks is controversial. Despite likely benefits of healthy soils and sustainable farming practice from increases in soil carbon, there is uncertainty in the likely scale of such sinks, the rate at which they can be built, their persistence in the context of dynamic farming systems exposed to the vagaries of the Australian climate and the consequences of seeking credits for such sinks at the same time as accepting liability for any future reductions in soil carbon.

Current Australian greenhouse gas inventory protocols do not include changes in soil carbon levels under agricultural practices. They could be included in future under article 3.4 of the Kyoto protocol. However, inclusion of "additional activities" would have to be comprehensive – i.e. on all agricultural land, not just land subject to a specific carbon storage activity and they would have to capture impacts of both natural and man-made changes. Significant emissions liabilities are thus possible on some agricultural land and in some years, such as after a major drought.

Agronomic research over many years studying soil organic matter changes under different farming systems and management regimes suggests that agriculture has been much more likely to run soil carbon down than build it up. There is extensive evidence of the rundown in soil carbon following land clearing and in particular following cropping – e.g., internationally, Petersen et al, (2005); Kirchmann et al., (1994) and in Australia, Dalal and Mayer, (1986); Skjemstad et al., (2001). Examples of soil carbon build-up in the Australian literature are less easy to find and are generally associated with pasture phases in a farming system or switching from residue burning to retention (Dalal et al., 1995; Whitbread et al. 2003). Internationally, there are excellent long-term data sets that show how soil organic carbon can be built up in response to treatments such as fertilisation and straw incorporation, green manuring and farm yard manure application (see examples reported by Petersen et. al., 2005).

A range of models have been used to study soil carbon or soil C/N dynamics – e.g., Roth C (Jenkinson, 1990), APSIM (Probert et al., 1997, Keating et al. 2003), CENTURY / DAY-CENT (Parton et al., 1998), G'DAY (Corbeels et al., 2005), and CN-SIM (Petersen et al., 2005). Alternatively, simple mass balance and kinetics calculations can be used to illustrate the scale of soil carbon changes that might be possible based on a systems-level understanding of plant-soil interactions (Baldock and Broos, 2008).

In reviewing soil C sequestration potential globally, Hutchinson et al. (2007) conclude that, while rates of soil C increase in the range 0 to 1 tonnes C / ha / year were possible, most results were in the 0.1 to 0.3 tonnes C/ha/yr. These rates are broadly consistent with those suggested as possible under very favourable conditions of additional C inputs (Baldock and Broos, 2008). In terms of management factors that promote increased soil C, Hutchinson et al., (2007) identify practices such as increasing cropping frequency and thus reducing bare fallow, increasing use of forages in crop rotations, reducing tillage intensity and frequency, improved fertility of cropland/pasture, better crop residue management, and adopting agroforestry. We would add to this list; additions of farm yard manure and shifting from cropping systems to permanent pasture systems.

The significance of soil carbon build-up in terms of future economic returns is also worthy of examination. Rates of soil carbon sequestration between 0.25 to 1.0 t C/ha/yr might represent asset values of between $36-147 /ha/yr if soil carbon was recognised and valued at $40/t CO_{2-} (Table 1). However, the likely economic significance of this carbon storage is diminished when one recognises that the nitrogen that needs to be incorporated in soil organic matter is likely to be worth more that the carbon at current N fertiliser prices. This analysis ignores the other nutrients (in particular P and S) that would also need to be sourced and incorporated into the soil microbial and humic pools to achieve an increase in soil carbon. This analysis is not intended to suggest that building up soil organic matter and nutrient reserves in soil organic matter would not be a desirable objective – many benefits would flow from higher soil organic matter. It does however suggest that "there is no free lunch", and a narrow pursuit of soil carbon sequestration as a source of income in farming is unlikely to deliver the overall economic returns expected by many.

Table 1. Indicative value of carbon storage (at A$40/t CO_{2-e}) for different rates of carbon sequestration together with the likely amount and value of nitrogen associated with this carbon sequestration, assuming C:N ratio of 12 in soil organic matter and an N value of $2/kgN. Shaded cells represent rates of soil C build-up that are most likely to be achieved under favourable conditions – exceptional levels of organic matter input would be needed to achieve higher rates of sequestration.

Change in soil carbon		Value of C sequestered	N required	Value of N stored in soil organic matter
t C/ha/yr	CO_{2-e}/ha/yr	A$/ha	kgN/ha	A$/ha
0.1	0.37	$ 14.67	8.3	$ 16.67
0.25	0.92	$ 36.67	20.8	$ 41.67
0.5	1.83	$ 73.33	41.7	$ 83.33
0.75	2.75	$ 110.00	62.5	$ 125.00
1	3.67	$ 146.67	83.3	$ 166.67

Agri-environmental stewardship

Recognition of the "non-production" dimensions of agricultural landscapes have been growing in significance over the past decade. Markets and incentive schemes are also beginning to emerge for "ecosystem services" that can be supplied by land managers to other parties, often governments or public good NGOs. Such schemes are variously referred to as agri-environment scheme (Europe), working-land conservation programs (USA) and environmental stewardship schemes (Australia). Across all OECD countries, Paris (2004) estimates that agri-environment measures directly account for only 3-4% of total producer support (Figure 13).

Funding of agri-environment schemes is growing in Europe (from close to zero in 1993 to €2 B p.a. in 2003), driven by a policy position around the "multi-functional" role of rural landscapes where food production, wildlife conservation and non-production economic benefits, such as agri-tourism and recreational space for urban communities, co-exist (EC, 2005). These schemes have been developed with two broad objectives, namely; (a) reducing environmental risks associated with modern farming and (b) preserving natural and agricultural landscape values. Specific activities supported vary widely but include actions such as;

- reducing fertiliser or pesticide inputs
- cropping systems that reduce nitrate leaching
- retention of crop residues to favour bird populations
- maintenance of traditional farming practices that have environmental benefits (such as retention of hedgerows etc).

These schemes average about half of the EU rural development budget and cover about 25% of agricultural land, although there is considerable variation in the penetration of such schemes from country to country (EC, 2005). Despite this large and diverse application of agri-environment schemes in the EU, the total budget spend of €2B p.a. represents around 1% of gross value of farm production (Hajkowicz, in press) and the bulk of EU support for agriculture (>95%) remains associated with "input – output" style subsidies that are production related.

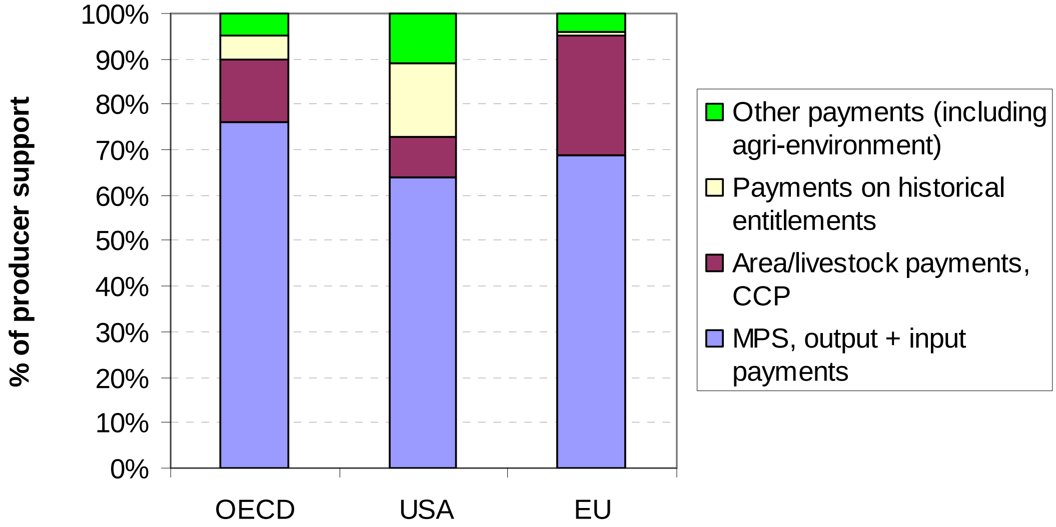

Figure 13. Breakdown of total agricultural support schemes in OECD, EU and USA (after Paris, 2004).

In the USA, the major programs initially focused on taking environmentally sensitive agricultural land out of farming (land retirement programs) with a more recent swing towards supporting conservation outcomes on "working land" (Figure 14). Land retirement programs (initial called the Conservation Reserve Program – CRP) generally remove land from agricultural production for a long period (at least 10 years) or, in some cases, permanently. In 2004, there were 34.9million acres (14M ha) of land taken out of US agriculture via various elements of the conservation reserve program, representing approximately 4% of the 930 million acres (370M ha) of all US farm land (ERS, 2007a).

The major "working-lands" program has been the Environmental Quality Incentives Program (EQIP) representing US$5.8B over the 2002-2007 period. Working-land programs provide technical and financial assistance to farmers who initiate or maintain conservation practices on land in production. Typical activities being supported include conservation planning and monitoring, soil and water conservation investments and cost sharing for protection of wildlife habitat. More recently, "agricultural land preservation" programs have commenced to support the purchase of development rights to keep productive farmland in agricultural use.

In Australia, there is uncertainty about the extent to which ecosystem service markets or incentive schemes might influence the future direction of Australian agriculture. Recognition is growing that agricultural land and farming regions have values that extend beyond commodity production. The "multifunctional" nature of agricultural land (Holmes, 2006) is a reality within distances of 50-100 km of the coast (from Cairns to the south and west to Geraldton) and especially for lands in close proximity to the major cities (Barr, 2005). More broadly since 1990, there has been a rapid rise in government spending on natural resource management (Figure 15). The focus has shifted over time, from an initial concentration on the Landcare model of knowledge exchange, attitudes and awareness and voluntary community participation (Campbell, 1994) to a stronger focus on regional NRM planning and institution building, often associated with statutory powers and significant budgets for regional NRM investments on major conservation and NRM challenges (such as salinity and biodiversity protection).

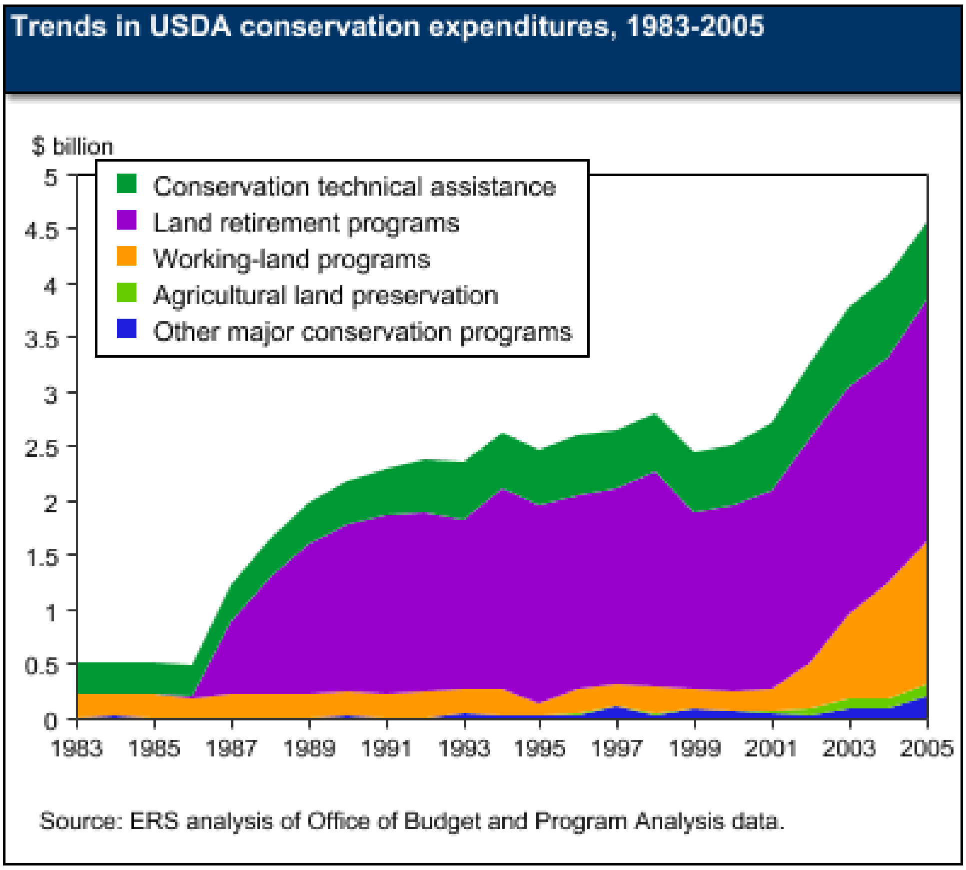

Figure 14. Trends in US conservation expenditures (ERS, 2007b)

Hajkowicz (in press) estimates that Australia's natural resource management expenditure of approximately 1% p.a of gross farm receipts is commensurate with other OECD countries. Expressed in terms of expenditure per unit of agricultural land (443M ha in Australia, including extensive rangelands, ABS 2007) or arable crop land (24M ha), the expenditure captured in Figure 16 represents A$0.63 per hectare per year for all agricultural land and A$11.60 per hectare per year for crop land. In Europe, Hajkowicz (in press) estimates the agri-environment expenditure in 2003 (EC, 2005) was A$16.89 per hectare per year. Similar calculations for the United States show expenditure on conservation programs under the US Farm Bill at around A$15.39 per hectare per year (Lubowski et al., 2002; USDA, 2007).

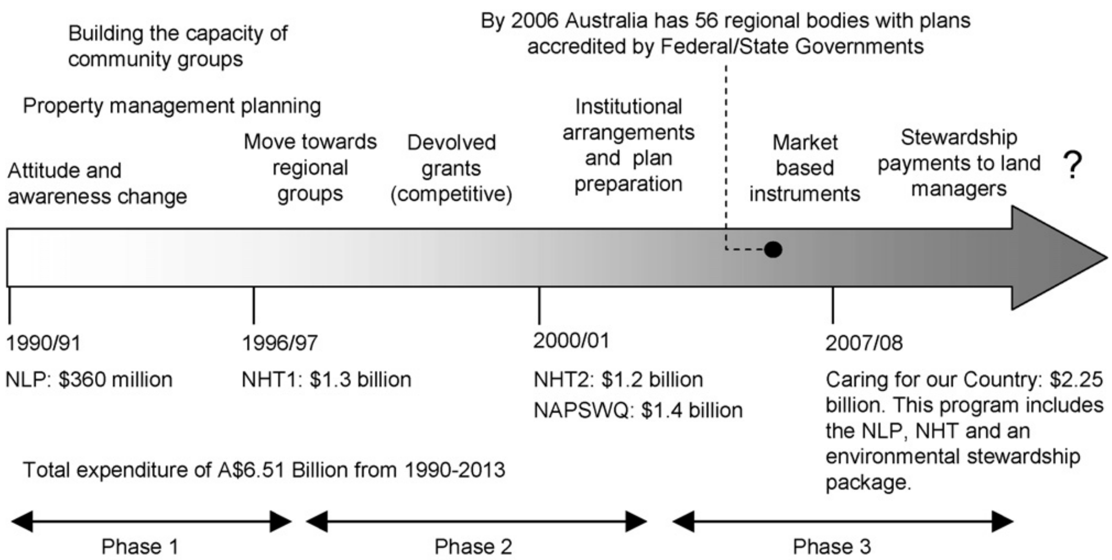

Figure. 15. The evolving focus of Australian natural resource management programs (Hajkowicz, in press)

While Australia is investing public monies in pursuit of NRM and other environmental outcomes in rural regions, the investment per unit area is lower than in the EU or the US due to the more extensive nature of the Australian agricultural landscape combined with our historically low levels of public subsidy to the agricultural sector (OECD, 2008c). However, Australia has a relatively small number of farmers and so, if environmental services were in high enough demand and if land managers could efficiently provide them, the “non-production” dimension of agriculture may grow. In fact, there is a growing interest in landholder provision of “environmental services” and in market-based instruments as economically efficient mechanisms for public procurement of such services (Reeson, 2008). In 2007, an Environmental Stewardship Scheme was initiated as a pilot program (A$50M over 4 years) with an initial focus on biodiversity conservation in the threatened grassy box woodlands of eastern Australia. The focus is the ***“****long-term protection, rehabilitation and improvement of targeted environmental assets on private land or impacted by activities conducted on private land”*. The intent is to use market based approached to purchase environmental stewardship services from private landholders over extended contracts (up to 15 years).

New regions

Australian agriculture has a long history of broad-based innovation in crop, pasture and livestock activities, including a dynamic mix in enterprise composition in response to market forces and geographic shifts in enterprise composition and extent. In regard to the latter, the two current prospects are (a) expansion of grain cropping into the higher rainfall zones in southern Australia and (b) expansion of agriculture in northern Australia.

The higher rainfall zone (HRZ) of southern Australia covers approximately 20M ha, of which approximately 4M ha are thought to be arable (Zhang et al., 2006). The HRZ is defined as the areas where annual rainfall is between 450 and 800 mm in Western Australia and between 500 and 900 mm in south-eastern Australia with a growing season length of 7–10 months (Figure 16).

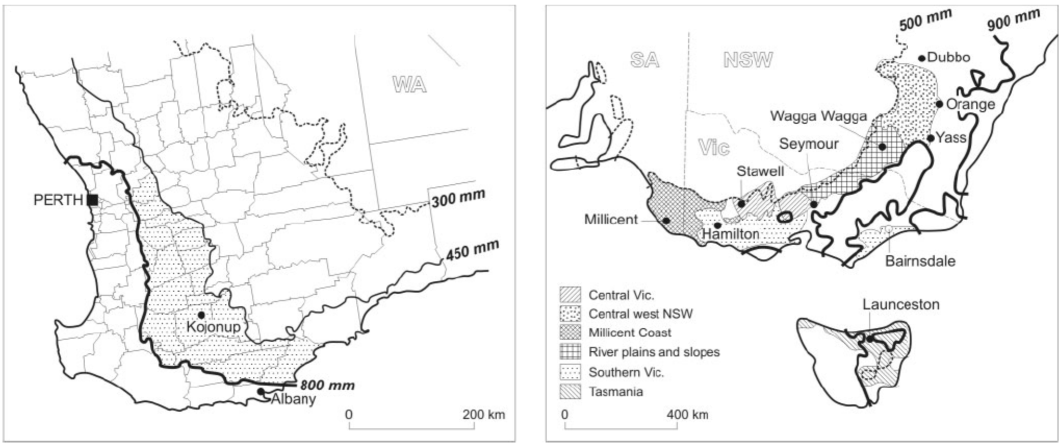

Figure 16. The high rainfall zone in southern Australia (sourced from Zhang et al., 2006).

An expansion of crop production into traditional grazing areas in the HRZ is now possible through the development of adapted premium-quality wheat varieties, by significant advances in the productivity of dual-purpose crops which have both grain cropping and grazing potential, and by agronomic practices which address issues such as waterlogging, soil acidification, nutrient leaching and soil erosion (eg. raised beds). Such expansion has the potential for significantly increasing profitability and income stability of farming enterprises in the HRZ zone as well as offsetting possible climate change related loss of production from irrigation areas and/or the drier margins of the wheat-sheep belt. Wider sustainability issues include the biodiversity implications of converting low-input pastures to cropping fields and the wider social and economic dimensions of change in the industry mix over such large regions.

Attention has turned to northern Australia in recent times as the water constraints for agriculture in southern Australia have become more acute. However, prospects for agriculture in northern Australia have tantalised many for almost 100 years, yet the challenges have been considerable (Davidson, 1972; Greiner and Johnson, 2000). Over time, many of the direct challenges of poorly adapted agricultural varieties and management practices have been addressed (Carberry et al., 1996), but significant economic (high costs, long distances, limited markets) and social (skills, infrastructure, Indigenous aspirations) hurdles remain. In addition, despite the vast land areas involved, the availability of significant areas of contiguous quality agricultural soils has been a major constraint and increasingly the intrinsic value of the natural ecological assets are being more widely and deeply recognised.

The current re-examination of northern Australia is seeking to build a refreshed knowledge base for further consideration of agricultural development options in the context of other development trajectories for the region. An initial investment is in the Northern Australia Water Futures Assessment (www.environment.gov.au/water/action/development/index.html) which will provide data on the water resources of the northern Australia landscape. One view gaining some credence is that the soils, environment and society of northern Australia might be better suited to smaller scale development activities located in favourable niches in the landscape rather than large scale attempts at broadscale cultivation based on traditional irrigation development. While economies of scale and the "tyranny of distance" remain real constraints, there are solid physical, ecological and social reasons why such alternative development pathways may be preferable.

Emerging threats

While there are favourable indicators and emerging opportunities for Australian agriculture, there are also some big unknowns or perhaps some warning bells ringing. Climate change, water availability for irrigated agriculture, energy and input costs and degradation of soil and natural resources are real concerns to Australian agriculture. Likewise, shortages in relevant skills and human capital for agriculture and in the viability of rural communities are threats of emerging importance.

Climate change clearly represents a large source of uncertainty that will touch on many aspects of agricultural productivity and practice in Australia (Howden and Crimp, 2008). However, adaptation to Australia's often extreme and variable environment has been central to agricultural research and farming practice from the outset and maintaining or enhancing adaptation efforts appears more important than ever with the prospect of climate change. In particular, continuing effort directed towards better managing our landscapes under climate variability will remain a core element of any climate change adaptation program.

Current indications are that water yields in our major river systems used for irrigation may be particularly sensitive to climate change with little doubt that modest rainfall reductions will result in less runoff and water yield for irrigation. While levels of uncertainty remain high, current best estimates for our major irrigated agriculture basin, the Murray Darling, suggest 10-20% rainfall declines could be associated with 20-40% reductions in water availability for irrigation (CSIRO, 2008). Such impacts will have significant impacts as the agricultural sector is by far the largest water consumer in the Australian economy, accounting on average for almost 70% of the country's annual use of extracted water (approximately 10,000 GL in 2003-04) by rural, industry and domestic sectors (OECD, 2008b). Although it occupies only 0.5% of all agricultural land (2.4 million ha in 2003-04), irrigated agriculture generates around 23% of the gross value of all agricultural production, or A$9 billion in 2003-04. Irrigated horticulture contributes 52% to this total (using 19% of irrigation water), with irrigated pastures and irrigated broadacre crops, traditionally cotton and rice, contributing around 48% (using 81% of irrigation water). Each of these industries is currently feeling the threat of reduced water availability and is considering a future that is different to the past.

The extent to which agricultural input costs are sensitive to energy prices varies across enterprises. For instance, Keogh (2008) estimates that a 10% increase in energy-related input costs increases input costs by 3% on average, but by 5% for cropping specialist operations. While direct energy use (fuel and electricity) is estimated at around 7 % for livestock farming and 11% for cropping, these figures rise to 17% and 39% respectively when other energy-dependent input costs such as fertiliser, freight, agro-chemicals and contracting activities are included (Glyde, 2008). Cropping intensive industries have even higher levels of exposure to energy-related costs (up to 45% of total input costs) (Figure 17). At the moment, these cost increases have not yet flowed through to downward pressure on farmers' terms of trade because of the "boom" in soft commodity prices. However, the agricultural sector is now much more vulnerable to falls in commodity prices if relatively high energy costs persist under pressure from global energy demand, peaks in oil production and greenhouse related imperatives to reduce fossil based energy use.

The National Land & Resources Audit in 2000 rang a number of loud warning bells over issues of natural resource management and the health of our soils that underpin agricultural productivity (NLWRA, 2001). Soil degradation issues such as erosion, salinity and acidification have not gone away, even though in recent years the debate in the public and science communities has been dominated by climate change, drought and irrigation supplies and the imperatives around greenhouse gas mitigation and carbon sequestration. Thus, for instance, the threat salinity poses to our agricultural landscapes and aquatic ecosystems remains despite the prolonged sequence of dry years possibly dulling our focus on this issue in terms of the appearance and spread of salinity in agricultural fields. Past estimates were that 2.1M ha of agricultural land are already degraded by salinisation and this could spread to 10-15M ha in future years (Hatton, 2001). Likewise, while soil erosion was a major focus of our soil resource concerns in the late 20th Century, with erosion rates in much of the agricultural lands ten times greater than the estimated average natural rate of erosion (NLWRA, 2001), the focus of research and extension efforts seems to have shifted from this threat.

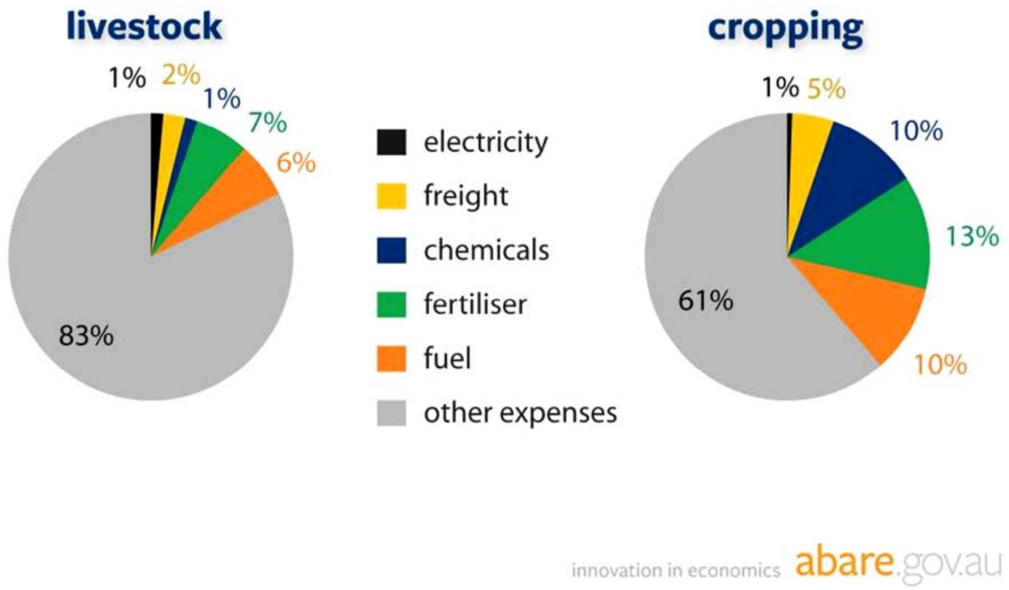

Figure 17. Average share of emission intensive inputs (i.e. energy related) as a fraction of total input costs based on 2005-06 farm survey data. (reproduced from Glyde, 2008)

Acidification has never achieved a high level of focus as a pressing NRM issue, yet it continues and could be seen as something of a “sleeper” issue that is going to seriously challenge us in future years. The National Land and Water Resources Audit (NLWRA, 2001) estimates that *approximately 50 million ha, or about 11% of all agricultural land, has a soil pH value of less than 5.5*. That is many-fold more land than is affected by soil salinity, yet the NRM challenge associated with soil acidification has not received widespread recognition. Moreover, without corrective action the area of land affected could increase to 99 million ha over the next decade. To put the scale of the issue in perspective, the NLWRA estimates that to raise the pH of all soils in Australia to 5.5, a one-off application of 66 million tonnes of lime would be required. The NLWRA estimates current agricultural lime use at nearly 2 million tonnes per year, which is insufficient to deal with existing acidity problems, let alone continuing soil acidification.

Finally regarding the soil resource, our understanding of soil biology remains woefully inadequate and agricultural science has yet to consistently develop an understanding that soil biological processes under modern farming systems sometimes get out of balance and end up as a constraint to productivity. There are a number of examples of such impacts in Australian agriculture – e.g. with sugar (Garside et al., 2005) and wheat (Kirkegaard et al., 1995) – and this domain will continue to be one of further discovery as new technologies provide the means to better characterise the function of the soil biota and the consequences of its poor management for agricultural performance.

Lastly and critically, access to skills and human capital in agriculture is a looming crisis. Leigh (2008) reports a decline of more than 18% in student enrolments in agricultural courses in Australian universities in the period 2001-2006 and that, while the number of jobs for new agriculture graduates exceeds 2000, the projections for graduates over the coming few years is less than 1000. The Australian Council of Deans of Agriculture believe the capacity is present within the higher education sector for doubling the production of agricultural graduates (Leigh, 2008) although anecdotal evidence in the research sector suggests critical skills gaps are appearing. Recruitment of skilled researchers in the disciplinary areas of soil science, agricultural economics, farming systems analysis and modelling is difficult in the current skills environment.

Pathways for Australian Agriculture

We have examined four distinct "emerging opportunities", namely biofuels, carbon farming, environmental stewardship and new production regions. We have also briefly recognised five threats, namely climate change, reduced irrigation water supplies, higher energy costs, degradation of natural resources and loss of human capital.

While the four emerging opportunities will all have a place in the future of Australian agriculture, we don't see any of them completely transforming the nature of agriculture itself in the near term. This is because they are overshadowed by the largest emerging issue, which is both a threat and an opportunity – that is the continued focus of Australian agriculture on efficient use of resources in food and fibre production and an increased effort on breaking away from the emerging productivity plateau. This situation will continue to be supported by global imperatives around food production in the years ahead. The pathway forward will, of necessity, involve a re-shaping of agricultural practices to changing balance in input costs and greater attention to soil health and efficient use of water and nutrient resources.

Three specific pathways are proposed to address productivity improvement. The first is to improve the agronomic performance of average growers who invest as much as the better growers but achieve poorer returns. They may have the right machinery, tillage systems, fertiliser and water input regimes to achieve good yields, but fall short in their agronomy and business management. Their transition to performing on a par with the better growers will likely require the provision of confronting evidence of their inefficiencies and access to better agronomic advice. This pathway has been a significant source of traditional productivity improvement for industry.

One clear example of an opportunity along this first pathway is to improve current practices in the production of irrigated grains. According to Toohey (2007), the current average yields (3 t/ha) and water use efficiency (10 kg/mm/ha) of irrigated wheat in southern NSW is disappointingly low and significantly below the 5-8 t/ha yields that could be expected under supplemental or full irrigation (Lacy and Giblin, 2006). With traditional acreages in Australia of rice and cotton significantly reduced due to low water availability, and with relatively high grain prices, there is opportunity now to increase the area and close the yield gap for irrigated grain simply through improving the practices of growers using existing agronomic knowledge.

A second pathway is to encourage good growers to adopt the practices of those growers operating further up the efficiency curve. These growers accept higher risk through higher investment with expectations of higher yields and returns. Essentially, this route is for those growers who currently choose to accept lower returns from lower investments and who need to be convinced that the increased investment needed to achieve the returns of the best growers justifies their higher risk exposure. Strategies to enable these growers to better understand and manage such risks, especially in dealing with climate variability (e.g. Hunt et al., 2006), will greatly assist in this transition.

The third pathway is to work with the best growers to discover practices which increase returns for little added risk. For a region's best growers to move along the current economic efficiency frontier to higher returns will likely require greater investments and thus greater exposure to downside risk. The fact that these growers choose not to maximise yields and returns suggests that the needed investment is probably foolhardy under their economic environment and with existing agronomic norms. If this assumption is correct, then the only real option for these growers is to break away from the current efficiency frontier by creating new production systems and/or practices which can increase returns for little added risk. Such is the hope of technologies such as precision agriculture or biotechnology.

In a recent study, Robertson et al. (2006) quantified the economic benefits of precision agriculture (PA) on six pioneering farms from the Australian wheatbelt. Across these case studies, the estimated annual benefits from PA ranged from $14 to $30/ha with the initial capital outlay recovered within 2-5 years. Specifically for variable rate fertiliser management, benefits ranged from $1 to $22/ha across the six farms. Looking further to the future, the targeted harvesting of agricultural crops based on quality attributes and thus differentiated markets offers the next step in PA beyond variable application of inputs. For example, Bramley (2007) reports evidence of economic benefits to grapegrowers and winemakers through the adoption of precision viticulture, especially with respect to selective harvesting. These benefits accrued from harvesting on separate dates and into different bins on the same day and resulted in the production of differentiated end products. Such new practices are needed to continue the productivity and economic viability of agriculture in Australia.

It is worth reinforcing the fact that all these "pathways" for productivity enhancement, will play out in a new environment in which there is a cost on greenhouse emissions and this cost will influence profitability and productivity drivers.

Conclusions

We live in an increasingly inter-connected world – one in which it is impossible to think about trajectories for Australian agriculture without examining the global forces at work – and the threats and opportunities emerging.

Agricultural R&D has been the engine room of agricultural productivity advances over the last 50 years. The spillovers of agricultural R&D from developed countries to developing countries are well documented (Pardey et al, 2006; Alston and Pardey, 2006) but there is evidence this global productivity engine is "running out of gas". Shifts in the focus of agricultural R&D in developed countries away from productivity issues in food crops is thought to be one of the reasons for this, but reductions in research funding to the international agricultural R&D system (CGIAR) as well as a shift away from agricultural production in development assistance programs are all seen as part of the set of forces at work. In Australia, we also see signs that agricultural productivity gains are beginning to plateau – a situation that is likely to be exacerbated when a cost is assigned to greenhouse gas emissions and as the availability of irrigation water reaches new lows and its price reaches new highs.

Because the global atmosphere does not recognise national boundaries, Australia's agricultural future is intimately intertwined with, on one hand the global imperative to reduce greenhouse gas emissions and on the other hand, the climate shifts that are already likely to have been set in train. We will undoubtedly be hearing more on the mitigation and adaptation challenges facing Australian agriculture which will cover a complex set of issues including;

- higher costs of agricultural inputs with high exposure to the energy sector (fuel, electricity, fertilisers, agro-chemicals etc),
- direct exposure to any broadly based policy intervention aimed at putting a cost on greenhouse emissions,
- climate shifts reducing water supplies to both irrigated or dryland agriculture and higher temperatures exacerbating agricultural drought,
- shifts in the adaptation and competiveness of agricultural and forest industries at regional and international scales and the implications in terms of infrastructure needs and utilization and social and economic adjustment.

These inter-connected set of national and global challenges (and opportunities) around a resource-constrained world with a changing climate that is still in need of continuing advances in agricultural productivity are going to place a heavy demand on human skills and ingenuity. At the very time the demand for the integrative skills of the "21st Century" agronomist is increasing, we see de-skilling in our University agricultural sector, a major exodus from public sector research institutions associated with the "baby boomer" retirement wave and relentless squeezing of budgets. We have clearly failed to create the circumstances where our children see "agriculture" as anything other than a low paid relic of the last Century.

Agronomy has always been an integrative science and 21st Century agronomy is going to place even greater demands on our abilities to draw together disciplinary knowledge in plant and soil sciences and connect with climate and atmospheric sciences, ecological sciences and social and economic sciences. The pathways for impact of agronomy have grown well beyond the traditional linear transfer to extension and farmer. The demands for well informed policy development at government or industry scale are stronger than ever and integrative and predictive agronomy has an important part to play. Our sole reliance on "white peg agronomy" is well gone and measurement and modelling at a range of temporal and spatial scales are now the stock tools of trade.

What a fascinating and challenging time for agronomy. We need to make sure it rises to the new challenges.

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