NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Climate change research priorities for NSW primary industries
Discussion paper

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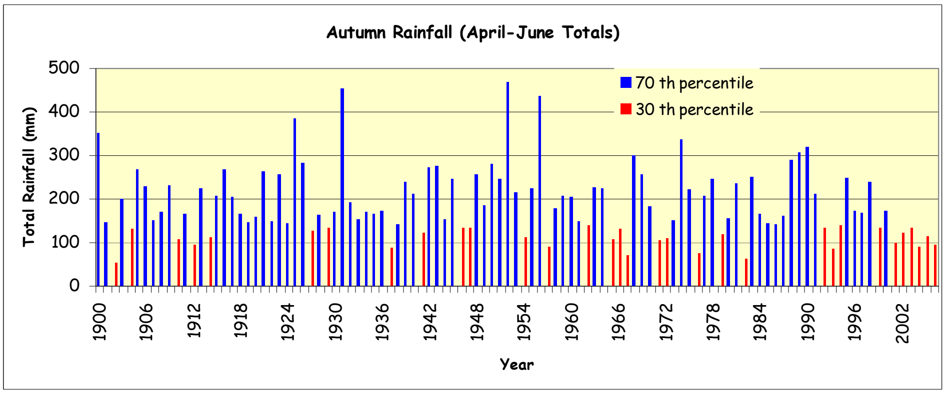


Figure 13. Autumn rainfall totals for the Yass area (grid box bounded by 148.5°E to 149.5°E and 34.5°S to 35.5°S) (source: BoM 2007a).

The extent to which these observed changes in the climate of NSW are due to anthropogenic greenhouse gas emissions is unclear; it is likely that global warming is responsible for the temperature changes; the causes of rainfall trends are less certain (Nicholls 2006).

8 PROJECTED CLIMATE CHANGES IN NSW AND THEIR IMPACTS ON PRIMARY INDUSTRIES

Based on regional interpretation of global climate models, Hennessy et al. (2004a, b) assessed future changes in the NSW climate in terms of average conditions and extremes. The following information is summarised from these documents.

In terms of average temperature changes anticipated by 2030, the greatest warming (relative to 1990) is expected in western NSW (0.2° to 1.8°C in the Central West) and the Northern Tablelands (0.3° to 2.1°C), with the least warming projected for the southern and coastal areas (0.2° to 1.6°C). The spring and summer seasons are expected to experience the most warming, with the least expected in winter.

By 2070, the projected ranges increase considerably:

- 0.7° to 4.8°C in coastal and southern regions
- 0.7° to 5.6°C in the central west
- 0.9° to 6.4°C in the north.

These projections are based on a series of scenarios (see footnote 3) including options of:

- no policies to reduce greenhouse gas emissions
- stabilisation of CO_2 concentrations at 550 ppm by the year 2150
- stabilisation of CO_2 concentrations at 450 ppm by the year 2090.

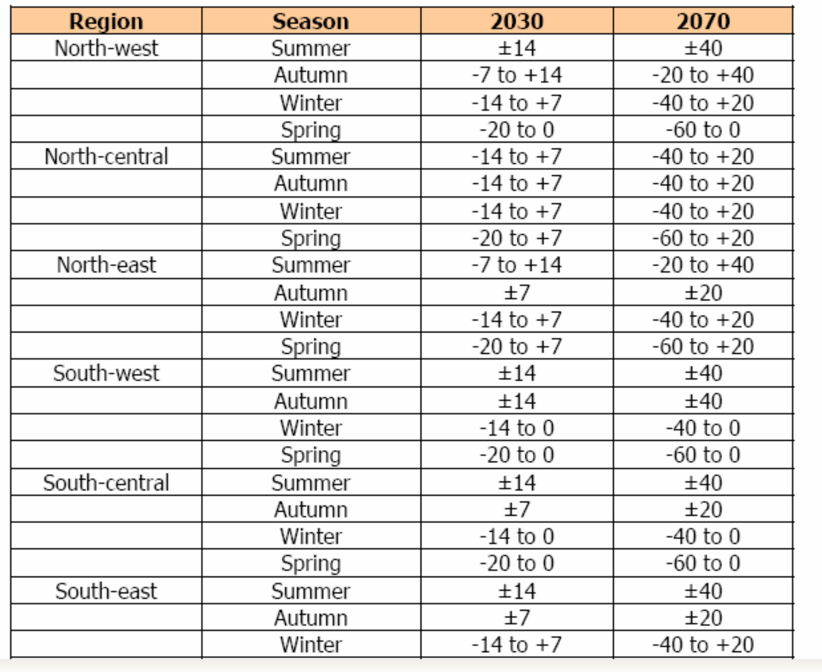
As it is impossible to be certain about how the future will unfold with respect to mitigating greenhouse emissions, these scenarios provide story lines for a range of future responses. It is these futures that are used to drive the global climate models.

Today the concentration of carbon dioxide in the atmosphere is around 375 parts per million and is rising by ~1.5 ppm each year (IPCC 2001a). Without mitigation measures the concentration of carbon dioxide in the atmosphere is predicted to rise to at least 650 ppm and up to 1200 ppm by 2100 (IPCC 2001a). However, if emissions are constrained to such an extent that CO_2 concentration in the atmosphere is stabilised at 550 ppm by 2150, the upper limit of warming is projected to be reduced by 23% by 2030 and 38% by 2070 compared with the business as usual scenario. Stabilising carbon dioxide at 450 ppm by

2090 would reduce the upper limit of warming by 25% for 2030 and 48% for 2070 (Hennessy et al. 2004a).

The projected changes in rainfall are less certain than those for temperature, with projections for both increases and decreases depending on the scenario used. There is, however, a general tendency for decreasing annual average rainfall over NSW, particularly for winter and spring. In autumn, the direction of rainfall change is uncertain over most of the state, with a tendency for decreases in the north and increases in the far west. Summer rainfall changes are uncertain over much of southern and western NSW, with a tendency for increases along the coast and in the north-east, and a tendency for decreases in the north-west (Table 3).

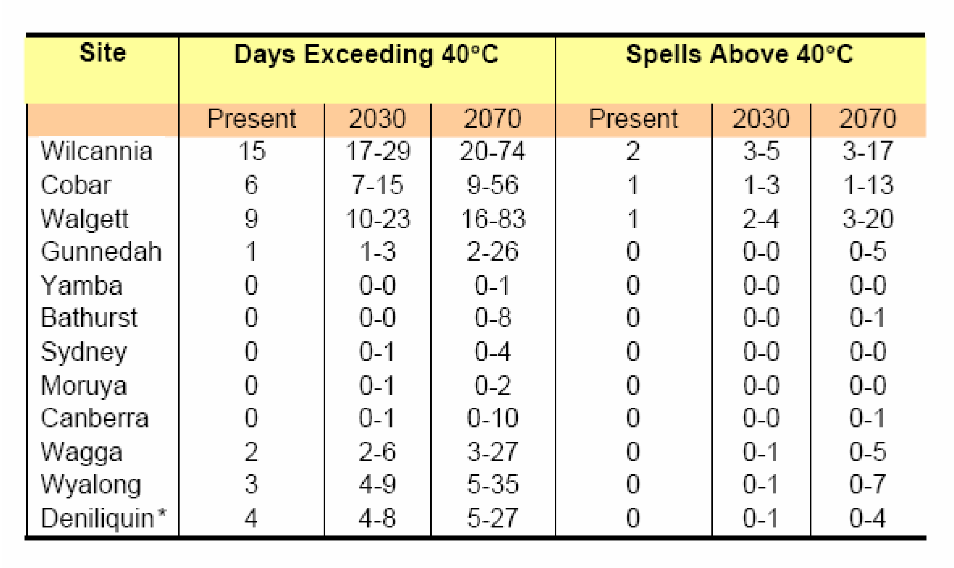
Table 3. NSW regional rainfall change (%) scenarios for 2030 and 2070, relative to 1990 (Hennessy et al. 2004b).



Region	Season	2030	2070
North-west	Summer	±14	±40
	Autumn	-7 to +14	-20 to +40
	Winter	-14 to +7	-40 to +20
	Spring	-20 to 0	-60 to 0
North-central	Summer	-14 to +7	-40 to +20
	Autumn	-14 to +7	-40 to +20
	Winter	-14 to +7	-40 to +20
	Spring	-20 to +7	-60 to +20
North-east	Summer	-7 to +14	-20 to +40
	Autumn	±7	±20
	Winter	-14 to +7	-40 to +20
	Spring	-20 to +7	-60 to +20
South-west	Summer	±14	±40
	Autumn	±14	±40
	Winter	-14 to 0	-40 to 0
	Spring	-20 to 0	-60 to 0
South-central	Summer	±14	±40
	Autumn	±7	±20
	Winter	-14 to 0	-40 to 0
	Spring	-20 to 0	-60 to 0
South-east	Summer	±14	±40
	Autumn	±7	±20
	Winter	-14 to +7	-40 to +20

As for rainfall, the impact on drought frequency is uncertain; drought may increase or decrease, though an increase is more likely, especially in winter and spring. By the year 2030, drought frequency has increased by about 70% for the worst case scenario (decreased rainfall), and has decreased by 35% for the best case scenario (increased rainfall). The range of uncertainty is much larger by 2070, when drought frequency could increase by more than 200%, or decrease by up to 70% (Hennessy et al. 2004b).

Table 4. The average number of days per year above 40°C at 12 NSW sites for present conditions (1964-2003), 40 years centred on 2030 and 40 years centred on 2070. A hot spell is defined as three consecutive days above 40°C.



Site	Days Exceeding 40°C			Spells Above 40°C		
	Present	2030	2070	Present	2030	2070
Wilcannia	15	17-29	20-74	2	3-5	3-17
Cobar	6	7-15	9-56	1	1-3	1-13
Walgett	9	10-23	16-83	1	2-4	3-20
Gunnedah	1	1-3	2-26	0	0-0	0-5
Yamba	0	0-0	0-1	0	0-0	0-0
Bathurst	0	0-0	0-8	0	0-0	0-1
Sydney	0	0-1	0-4	0	0-0	0-0
Moruya	0	0-1	0-2	0	0-0	0-0
Canberra	0	0-1	0-10	0	0-0	0-1
Wagga	2	2-6	3-27	0	0-1	0-5
Wyalong	3	4-9	5-35	0	0-1	0-7
Deniliquin*	4	4-8	5-27	0	0-1	0-4

*** At Deniliquin, present conditions refer to 1963–2002 (Hennessy et al. 2004b).**

Changes in rainfall intensity can potentially have a large impact on the hydrologic cycle, and therefore the water resource. In some regions, the projected regional average change is quite large (e.g. an increase of up to 34% in the March, April, May period by 2030 in the north-west); however, the changes need to be considered in conjunction with the current rainfall totals. If the current rainfall totals are high, moderate changes can have a significant impact on the hydrological cycle, whereas large percentage changes to a small total rainfall may have negligible impact. See Hennessy et al. (2004b) for the full suite of results for projected changes in rainfall intensity.

There are two broad approaches required to adequately model and assess the impacts of the projected changes in the climate outlined above, namely hazards-based and vulnerability-based methodologies. Both are important for assessing the impacts at an industry level or on a regional scale.

The hazards-based approach uses a top-down methodology, by which biophysical and socioeconomic conditions are analysed in conjunction with plausible future climate scenarios. The vulnerability-based methodology takes a bottom-up approach, by which the criteria (or critical thresholds) are based on socioeconomic or biophysical outcomes, and an analysis is conducted to determine how likely these criteria are to be met or exceeded (Lim 2004).

The hazards-based approach requires a downscaling technique to be applied to the General Circulation Model (GCM) outputs, in order to be able to make assessments at a regional level (e.g. the statistical downscaling technique described in section 5). A range of climate scenarios should usually be considered in conducting this type of impact assessment (IPCC 2001), which can be computationally intensive. Furthermore, the techniques for applying this methodology are still being developed; therefore, the bottom-up or vulnerability-based methodology is the optimum starting point for assessing the impacts of climate change on primary industries.

The climatic requirements for different agricultural systems and the phenology of plants and animals (i.e. the seasonal timing of their activities) as a function of the current climate are well understood, and have been comprehensively documented (e.g. Reid 1990). By assessing the variability of the climatic zones in which each of the production systems has been established, it is possible to define their ‘coping range’ in a stationary climate. The coping range is defined by the thresholds of the key climate variables that negatively impact on the productive capacity of the system being investigated.

The vulnerability-based assessment tests the capacity for the coping range to be extended by applying various adaptation strategies. The variables that need to be assessed in applying the vulnerability-based assessment include temperature, rainfall, wind, humidity, and derivatives of these variables, such as soil water and stream flow.

In NSW, increases in the incidence of hot days and spells of hot days (Table 4) will be significant for agriculture and forestry. The impacts for agriculture will include heat stress on animals and water stress on crops. Some irrigation systems designed for current climates may not be able to supply the peak demand associated with the change in hot spells. For forestry, increased hot spells are likely to lead to increased fire risk.

The impact of climate change on water resources is one of the most critical issues, as all models suggest an adverse effect on stream flow in the southern part of the country, particularly in the winter and spring, due to reduced rainfall, increased evaporation and increased competition for water.

Another variable important to primary production and likely to be affected by climate change is the timing of the onset of the different seasons. This onset or break of season is usually defined by an amount of rainfall received over a given time (as in the ‘autumn break’ – see Section 7) or by the sustained average daily temperature reaching a certain threshold. These changes are likely to influence the length of the growing season, and therefore production.

Climate change could also lead to increased incidence of existing pests, parasites and pathogens, and a possibility of exotic incursions. The horticulture, livestock and forestry sectors could be particularly susceptible to their southerly migration. Biological control of new pests and diseases will need to be considered as possible adaptation strategies to mitigate potential damage; however, we could observe less disease and damage in hotter, drier years.

The direct effects of climate change (reduced winter and spring rainfall and increasing temperatures), as well as its indirect effects (pressure on water resources, fire incidence), will have potentially serious negative impacts on most of the agricultural production systems in place in NSW. Understanding what these impacts might be is the starting point in a vulnerability-based assessment for each industry sector.

8.1 HORTICULTURE

Horticulture in NSW is a very diverse and rapidly expanding industry. The range of industries that make up the horticulture sector include fruit, vegetables, nuts, turf, extractive crops (essential oils) and cut flowers. The production systems across each of these individual industries are extremely diverse, ranging from large-scale vegetable, viticulture and citrus operations in the Riverina, through ornamental horticulture and fresh fruit and vegetable production in the Sydney Basin, Hunter Valley vineyards, deciduous fruit on the Tablelands, to the North Coast macadamia nut and banana plantations.

The coping range of each of the horticultural crops is determined by the climate in which it has developed. Hazelnuts, for example, require 1200 hours of chilling at 5° to 7°C, and if they experience < -5°C at flowering, the crop will be damaged. The quality and weight of the macadamia harvest is ideal when daily maximum temperatures are between 30° and 35°C from December through to February; conditions outside this range will result in a loss of production. Similarly, citrus will suffer a production loss when temperatures over 37°C are experienced. There has been little work done on documenting the adaptation strategies required to extend the coping range of each of these industries in the face of climate change.

Determining the effect of temperatures outside those normally encountered, coupled with increased carbon dioxide, are important areas of future research, particularly in the key horticultural regions of NSW (Pittock 2003).

A study conducted by Webb (2006) on the impact of climate change on vineyards suggests that season duration in all grape growing areas will be compressed, with harvest usually occurring earlier. Webb (2006) also projected a negative impact on grape quality (using economic returns as a surrogate) if no adaptation strategies are implemented. In the Riverina, a 16% decline in quality is projected for the minimum warming scenario, and a maximum decline in quality of 52% by 2030 for the maximum warming scenario. Projections for 2070, using the maximum warming scenario, suggest that vineyards will become economically unviable in the Riverina. Webb's (2006) modelling also showed a shift towards the south and coastal areas of suitable conditions for many varieties.

The adaptive capacity of the horticulture industries will be as varied as the industries themselves, and will depend on the investment cycle of the particular industry; for example, vineyards have a life of 30 years or more, posing a major challenge for adaptation (Pittock 2003).

8.2 PASTORAL FARMING

Much of the beef, dairy and sheep industry in NSW comprises pasture-based production systems. While research has shown that a rise in carbon dioxide tends to promote pasture growth, this could be counteracted by reduced rainfall; a 10% reduction in average rainfall is predicted to counter the effect of a doubling of CO_2 concentration in the atmosphere (Pittock 2003). If rainfall declines by more than 10%, the likely impact will be reduced pasture growth, which is not only important for animal production, but could also lead to potential environmental degradation of some grazing lands. In conjunction with the likelihood of reduced pasture growth, there is potential for increased variability of pasture production.

The nutritional quality of pastures is likely to decline, through a reduction in foliar nitrogen concentration due to elevated CO_2, reflected in the impact on crude protein and water-soluble carbohydrates. However, the interaction between CO_2 and the main drivers of plant growth (i.e. temperature, water and fertiliser) makes it difficult to determine the exact impact of climate change on nutritional quality.

Plants may differ in their ability to acclimatise to gradual increases in temperature, and the incidence of extreme temperatures outside the coping range may result in changes to the botanical composition of pastures. In the subtropics, C3 grasses (e.g. rye grass, used as winter forage for subtropical dairies) are vulnerable to both an increase in average and extreme temperatures in spring–early summer. Modelling has already indicated yield losses in spring (K Sinclair, pers. comm.). A shift in botanical composition towards C4 species (many of which have lower digestibility than C3 species) is likely, due to higher temperatures and the possible shift towards greater summer rainfall dominance. It is not, however, inevitable; a shift towards C3 species with increased CO_2 may be equally likely, and has been suggested as an underlying mechanism of the worldwide encroachment of C3 'woody weeds' in semi-arid rangelands.

In addition to these impacts on pasture yield and quality, increased temperature and humidity will impact directly on the productive capacity of grazing animals, particularly cattle. The temperature-humidity index (THI) is a measure of the heat stress on cattle, and hence a measure of their productive performance.

The impacts of increased heat stress in cattle include reduced grazing time (partly as a result of animals seeking shade), reduced feed intake, increased body temperature, increased respiration rate, and weight loss. In dairy cows, heat stress reduces milk yield, reduces milk fat and protein content, and decreases reproduction rates (Jones & Hennessy 2000). High-producing dairy cows are the most susceptible to increases in the THI. Heat stress days with THI > 80 lead to a substantial effect on reproduction of dairy cows, particularly for Holstein-Friesian. When assessing the impact of climate change on THI, it is important to assess, not just the change in the mean, but also the change in the number of extreme days (Howden et al. 1999b).

The response of beef cattle to THI is similar to the response of dairy cattle, although Bos taurus indicus cattle seem to be about 10% more tolerant than Bos taurus. All cattle require significantly more water when under stress. Significant stress is experienced at a THI of 80, and a recovery period is important in minimising production losses (Davison et al. 1996).

A cooling strategy, such as the provision of shade and sprinklers, is a key factor in minimising the impacts of increased THI for both dairy and beef cattle. The THI threshold at which a cow will generally start to be impacted by heat when no shade is provided is ~72. This can be increased to 76 by providing shade in feeding areas, and to 78 through the provision of shade and sprinklers (Jones & Hennessy 2000).

Implementing strategies to reduce heat stress is more practical for intensive livestock systems; however, shade infrastructure can be expensive for very large operations. Using sprinkler systems to reduce heat stress in dairy cows can also increase the risk of mastitis, because udders can become wet and dirty, creating ideal conditions for the growth of bacteria (Dairy Australia 2007).

For intensively fed (feedlot) beef cattle, heat stress is already a monitored health risk in mid to late summer. The risk is a function of the duration and intensity of heat load, together with the capacity for heat dissipation. A risk analysis program available to feedlot operators links with internet-supplied regional heat load index forecasts (www.katestone.com.au/mla). Climatic change leading to prolonged periods of sustained hot weather and greater peak temperatures can be expected to extend this risk period and increase feedlot operators’ reliance on such a service, which will allow them to invoke heat protection procedures (MLA 2007).

An additional risk from climate change to livestock industries, both intensive and extensive, is the potential for changing patterns of parasite risk to animals; for example, the potential for the ‘tick line’ (the cattle tick boundary) to move further south. Managing the impact of this increased parasitic risk to animals will require changes to operational practices, such as dipping and drenching.

Adaptation to climate change is likely to require more flexibility and improved management of seasonal risk. An example of a risk management strategy for the extensive livestock industries is the maintenance of a higher proportion of ‘disposable’ animals in the flock. Adaptation to increased heat stress could involve cross-breeding.

Other intensive animal industries, such as poultry and pigs, are also vulnerable to increases in temperature and the resultant heat stress on animals. Structures may have to be redesigned to accommodate the conditions likely to be encountered in a changed climate. An alternative strategy is to relocate to a more favourable climatic region. Either option will be expensive, with the latter having flow-on effects to local communities, such as changed employment options.

8.3 CROPPING

Wheat is the predominant crop grown in NSW, with ~3.9 Mha of wheat for grain being planted in 2004, which was 55% of the total area prepared for crop production (ABS 2005). The area of wheat production peaked in 1969 at just over 4 Mha, when 5.8 Mt were harvested. The peak harvest, however, was in 2000, with 8.6 Mt harvested from just 3.4 Mha. These variations are a result of continued improvement in varieties, cropping practices and technology. However, there has been considerable year-to-year variation in the yields and the area grown (Figure 14). This variability highlights the uncertainty already being managed in this important cropping system.

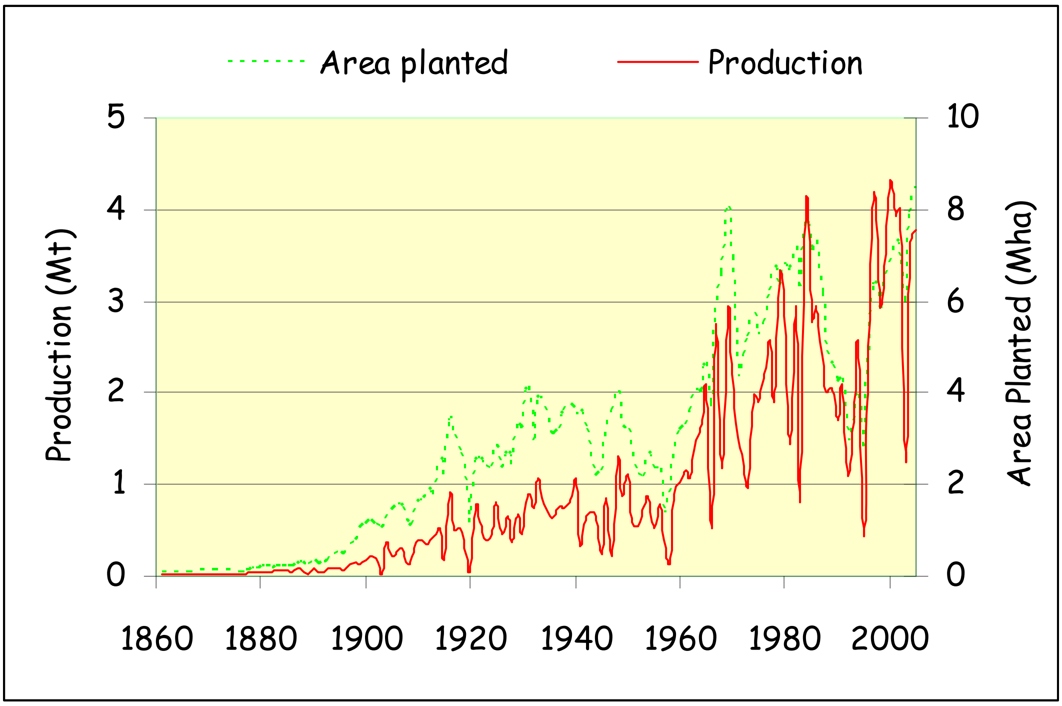


Figure 14. Wheat for grain, area (ha) and production (tonnes) in NSW (ABS 2005).

There have been only a few studies to date of the specific impacts of climate change on Australian wheat cropping systems. Most of these studies used the Agricultural Production System sIMulator (APSIM) wheat model, in conjunction with GCM outputs. The studies include an assessment of the conditional probability of not meeting the critical wheat yield threshold[7] in South Australia (Luo et al. 2005a), the effects of a changing climate on wheat cropping systems in northern NSW (Power et al. 2004), the impact on grain protein levels of doubled CO_2 in Qld (Reyenga et al. 2001), changes in wheat yields, grain quality, and gross economic margins at 10 sites across the Australian wheat belt (Howden et al. 1999a), as well as the increased likelihood of heat shock and the projected boundary changes of Australia’s viable wheat cropping areas (Reyenga et al. 2001). None of these studies considered the possible improvements that may be made through the adoption of adaptation measures.

The findings of these studies are diverse, with the impacts of temperature increases, rainfall changes and increases in CO_2 concentration varying markedly across different regions (Howden & Jones 2001). The authors projected that Western Australia has a high likelihood of significant yield reductions; conversely, north-eastern Australia has a high likelihood of moderate yield increases, although there is also a small probability of substantial yield reductions in this region.

The likely impact of climate change on wheat and sorghum production in central Queensland was studied by Potgieter et al. (2004). They concluded that large declines in yield (especially for wheat) were likely to occur by 2030, and recommended regional adaptation strategies (e.g. management practices, such as water conservation measures and adjusting planting dates and crop choice), as well as the development of more drought-resistant and more water-efficient crop cultivars, to mitigate the likely impact of climate change.

In analysing the impact of climate change on yields, it is also important to include a particular rate of improvement in variety adaptation. Breeding is a dynamic activity, and selections are going to be made as the climate changes are occurring. It is likely that some

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[7] A critical economic yield derived from current input costs, grain prices, and standard return on investment (3%) (Luo *et al.* 2003)

considerable compensation will occur, so that the selected varieties will be better adapted anyway (J Oliver, pers. comm.).

Luo et al. (2003) projected that the conditional probability of not exceeding the critical yield at Roseworthy in South Australia increased from 27% for current climate conditions to 35%–50% under a mid-range climate change scenario.

Howden and Jones (2001) included three NSW sites in their assessment of the combined effects of possible atmospheric CO_2 increases and the associated temperature increases and rainfall changes on the Australian wheat industry for the year 2070. The three sites spanned the southern (Wagga Wagga), central (Dubbo) and northern (Moree) inland regions. The results of this work indicate that the northern and central areas can generally expect beneficial impacts, but with a small risk of negative impacts. Combined, these two areas average 19% of the national yield. For the southern region of NSW, Howden and Jones (2001) predict a likelihood of largely beneficial impacts.

Though it is likely that climate change conditions will favour increased wheat yields across NSW, climate change is likely to reduce wheat quality as a result of increased carbon dioxide concentrations. Elevated carbon dioxide reduces the protein content of wheat grain, which can reduce feed value, particularly when used as a protein supplement. However, the amino acid imbalance in wheat (low lysine) generally means it is purchased as an energy source for the starch. A reduction in protein due to starch dilution could therefore enhance the feed quality (J Oliver, pers comm.).

Free air carbon dioxide enrichment (FACE) experiments are currently being implemented in Australia, to better determine the effect of elevated CO_2 on wheat growth (AGO 2007b).

The outputs of climate change modelling exercises depend on the input variables; it is, therefore, unsurprising that different scenarios are predicted. However, there does not appear to be any dispute over the prediction that much of NSW will experience hotter and drier conditions in the future. Therefore, a wider range of crop species and planting windows is likely to be needed to help spread the risk.

Sorghum is the most widely grown summer crop in NSW, accounting for 63% of the average area sown during the period 1992/93–2001/02 (F Scott, pers. comm.). Cotton, maize, mungbean, sunflower and soybean make up the other major dryland summer crop options. Although sorghum has many advantages as a summer crop (it is more drought-tolerant than maize), it prefers a soil temperature of at least 17°C during sowing, which means that sorghum is not normally sown in northern NSW before early October. In contrast to sorghum, maize can be planted when soil temperatures reach 12–14°C, so maize can be planted 4–6 weeks earlier than sorghum. In northern NSW, maize can be sown as early as late August or early September.

Sunflower is an alternative summer crop that can be sown at similar soil temperatures to maize, and so has a similarly wide planting window. However, risk of bird damage and uncertain prices make it less attractive.

Apart from using tactical sowing opportunities to take advantage of prevailing soil moisture options, summer crops can be sown early or late to avoid the stress of flowering and grain fill during peak summer temperatures. The wide range in the maturation rate of maize varieties allows growers to take advantage of early or late sowing opportunities under dryland conditions. Quicker maturing varieties can:

- take advantage of a full profile of soil water, minimising the risk of running out of water before the crop matures in low rainfall seasons
- beat the summer heat before tasselling, for spring plantings
- avoid frost damage to late plantings.

Dryland cotton has been produced in Australia in seasons in which the starting soil moisture is reasonably high and the outlook for rainfall is promising. Dryland cotton production has been extremely limited for the past few years, as these conditions have not been met. Reductions in rainfall due to climate change are likely to limit future dryland cotton production. Dryland cotton is grown in regions that experience moderate to high rainfall variability during the key January to March period (Ford & Forrester 2002), and increases in rainfall variability and extreme events due to climate change (CSIRO 2006) will further affect this production.

Climate change may exacerbate the impacts of weeds, pests and diseases, through increased prevalence and changes in geographic distribution. There is potential for increased rust incidence in crops and pasture species; however, a drier climate may *reduce* the impact of cereal diseases.

Irrigated Crops

Though only ~1.5% of agricultural land is irrigated in NSW annually, it accounts for an average of ~30% of the total agricultural production value (NSW Irrigators 2002). Nationally, irrigated farm profit contributes over 50% of total agricultural profit (CRC IF 2006).

In NSW, the majority of irrigation is carried out in irrigation schemes. These operate as companies, under licences issued by the Department of Natural Resources (now Department of Water and Energy). The major crops are cotton and rice.

Generally, irrigated cotton and rice together contribute over $1 billion to the NSW economy (CRC IF 2006). However, between 2000/01 and 2004/05 there were significant reductions in the value of irrigated cotton (from $930 million to ~$500 million) and rice (from $350 million to $178 million), as a result of reduced water availability.

The main genetic limitation to rice-growing is the cold sensitivity of the temperate varieties used in Australia. Deep watering is used as a strategy to ameliorate cool temperatures at the sensitive times around panicle initiation. Increased temperature under climate change will mitigate cold sensitivity, so the need for deep watering should be dramatically reduced. Hence, climate change may have some benefits for the irrigated rice industry. It may also permit alternative rice species to be considered.

Climate change is likely to have a number of key impacts on cotton production in NSW. Cotton is suited to warm climates; it is affected by temperatures below 12°C (cold shock) and above 36°C. Decreases in the number of cold days due to climate change, as predicted by the CSIRO (2006), may prove beneficial to cotton production; however, the associated increase in days above 35°C may be detrimental. Fibre quality of both irrigated and dryland cotton is significantly affected by both temperature and water availability. These impacts vary with the time of season and interactions with other variables. Because international markets are increasingly focused on optimal fibre quality, managing this important characteristic is likely to become a greater challenge to Australian growers as the climate changes.

Most of the Australian cotton crop and the entire rice crop are irrigated; however, production in recent years has been significantly diminished, due to greatly reduced water availability. Most cotton growing regions in NSW started the 2006/07 season with announced allocations of around 20% or less, and some regions had 0%. Reduced water supply reliability limits the options for alternative cropping systems, some of which may require large capital investments. Compared with alternative crops, cotton has one of the highest returns per ML of water used; therefore, it is unlikely that growers will move away from irrigated cotton production in the short term.

Both rice and cotton are irrigated predominantly by gravity-fed surface irrigation systems. These systems are less energy-intensive than pressurised systems, and have sufficient flexibility to allow production to be reduced in years of lower water availability.

The majority of vegetables grown in NSW are irrigated (83%), as are 75% of fruit and 83% of all grapes grown in NSW. The irrigated sector represents an important source of fresh food production, especially in times of drought, and also provides some stability for regional livelihoods.

In recent years, there has been a move to introduce more efficient irrigation systems for most of the irrigated commodities in NSW. When irrigation becomes more efficient, through either technology or improved practice, salts are concentrated in the rootzone. This can have a negative impact on production, and therefore needs to be managed. Related to this is the increasing reuse of water, which grew from 1% of all water supplied (134 424 ML) in 1996/97 to 4% (516 563 ML) in 2000/01 (CRC IF 2006). There is generally a higher salt load in reuse water and, when coupled with more efficient irrigation, the understanding of the movement of salt and nutrients in the rootzone and beyond becomes even more critical. This is a high priority research area for the CRC for Irrigation Futures.

Before use, most irrigation water is stored in dams, ranging from very large, government-managed storages (24 814 GL total capacity in NSW) to small, on-farm dams of only a few megalitres. In the current climate, up to 50% of stored water can be lost by evaporation before use. These losses are projected to increase over much of NSW, due to climate change; therefore, mitigating these losses is another priority area for research. The CRC for Irrigation Futures, in conjunction with the CRC for Polymers, is researching new polymer formulations, in an effort to improve their ability to mitigate evaporation.

Climate change is likely to increase pressure for irrigation to become more efficient. To be able to effectively meet this demand, there is an increasing need for improved technology that will enable systems to be managed and operated in a more responsive mode. The areas of focus range from the plant (plant-based sensors of water stress) to catchment-wide responses (remote sensing of crop evapotranspiration).

8.4 FORESTRY

Over the next 30 to 70 years (one to two plantation rotations) a number of climatic variables are predicted to change. The potential impacts of these changes on forests are not clearly understood, especially for Australian tree species under typical Australian conditions.

Based on international research carried out over the past 20 years, a certain amount is understood about the direct effects of increasing carbon dioxide concentration on plant growth and function. Doubling of carbon dioxide concentration generally leads to increases in plant growth of 10%–25% (Nowak et al. 2004; Luo et al. 2005b; Norby et al. 2005). Most of the research has been on Northern Hemisphere species under environmental conditions different to those typical of Australia. Furthermore, most research does not consider the feedbacks at the ecosystem level that need to be factored in when predicting effects on whole forests from results measured on individual trees/saplings. Importantly, plant physiologists and modellers alike now recognise that the effects of elevated carbon dioxide measured in experimental settings and implemented in models may overestimate actual field responses, due to many limiting factors, such as pests, weeds, competition for resources, soil water and air quality, which are neither well understood on large scales, nor well implemented in leading models (Korner et al. 2005; Ainsworth & Long 2005; Tubiello & Ewert 2002; Karonsky 2003; Fuhrer 2003). A handful of experiments are now in progress to directly measure forest ecosystem-level responses to increased carbon dioxide; however, these FACE (free air carbon dioxide enrichment) experiments are all being conducted on temperate species in the Northern Hemisphere.

The lack of field-based forest experimentation in Australia makes it difficult to predict the effect of climate change on Australian native forests and plantations. The Hawkesbury Forest Experiment, in which NSW DPI is a collaborator, is beginning to redress this deficiency (See section 10).

Where trees are not water-limited, climate warming is likely to expand the growing season in southern Australia; however, increased fire incidence and pest damage may negate some productivity gains. Productivity of exotic softwood and native hardwood plantations is likely to be increased by carbon dioxide fertilisation effects, although the amount of increase will be limited by feedbacks such as nutrient cycling (Kirschbaum 1999). Elevated atmospheric carbon dioxide is predicted to increase water use efficiency, which may offset negative impacts on growth in those areas in which rainfall is predicted to decline. Extreme heat may limit forest growth in summer, as observed in European forests by Angert et al. (2005) and Ciais et al. (2005). Carbon stock in soil organic matter and surface litter may decline due to faster decay in a warmer environment, though this could be offset by a higher rate of input through CO_2 fertilisation and reduced biological activity if soil moisture declines. Thus, the interacting effects of temperature and CO_2 on growth and heterotrophic respiration will determine the impact of climate change on the net carbon balance of forest systems. Better understanding of these interacting factors is required, so that forest managers can plan species selection, silvicultural management and breeding programs to cope with predicted changes in climate.

The actual climate tolerance of many Australian tree species is wider than the climatic envelope that they currently occupy; furthermore, natural distributions rarely extend to fill the current climate envelope (Jovanovic & Booth 2002). Increasing carbon dioxide concentrations, which change photosynthetic rates and water use efficiency, and which may affect the temperature response (Curtis 1996), will modify species climatic envelopes; so, although climate change will move climate envelopes geographically, it is not at all clear what effect this will have on species distributions. The relative effectivenes of the various seed disperal mechansims employed by different species will influence their ability to migrate as climate changes.

Australia’s south-east is recognised as one of the most fire-prone areas in the world, and fire management agencies have identified climate change as one of the most important strategic issues confronting fire managers in Australia (Bushfire CRC 2006). The danger posed by wildfire is dependent on the probability of a fire starting, its subsequent rate of spread, intensity and ease of suppression. Suppression is affected by the air temperature, relative humidity, wind speed, the properties and arrangement of the available fuel, and prior rainfall.

Climate change is likely to impact on wildfire risk, largely through its impact on climate extremes, rather than gradual changes in average temperature and rainfall occurring over decades. Internationally, there is great uncertainty associated with studies on the impact of climate change on forest fires (Lemmen & Warren 2004; Shugart et al. 2003). Current projections suggest that, in south-eastern Australia, the frequency of very high and extreme fire danger may increase by 4%–25% by 2020, and by 15%–70% by 2050, with greater changes predicted for the inland than for the coast (Hennessy et al. 2005). Lightning strikes are predicted to increase in tropical northern Australia, but the impact of climate change on their incidence in the south is currently uncertain.

In the longer term, changes in the distribution of flora as a result of climate change will also impact fire risk in native forests; for example, replacement of cool temperate rainforest with sclerophyllous forest would increase flammability (Bushfire CRC, 2006). Fire danger is predicted to increase in spring, summer and autumn, so periods suitable for prescribed burning are likely to be restricted (Hennessy et al. 2005).

Forest fires emit large quantities of carbon dioxide, as well as small but significant quantities of the greenhouse gases methane and nitrous oxide, and the greenhouse gas precursors CO and NO_x and NMVOC (IPCC 2005). Excluding carbon dioxide[8], forest fires (controlled fire and wildfire) contributed 4.4 Mt CO2-e in 2004, and 1.2 Mt in 2005 (AGO 2007c). Thus, management to reduce the incidence of fire could assist in the mitigation of greenhouse gas emissions. Indeed, some have advocated the inclusion of fire management as an eligible offset activity in the proposed National Emissions Trading Scheme (NETT 2006; see also Section 9.10); however, accounting for the impacts of fire management on greenhouse gas emissions will be complex, in that:

- if prescribed burning is used to reduce the risk of high-intensity wildfire, the emissions from prescribed burns must be balanced against predicted emissions from avoided wildfire

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[8] CO_2 loss during fire is considered to be balanced by CO_2 removal during forest regrowth, so CO_2 flux due to fire is not included in the national inventory.

- carbon dioxide emissions during fire are assumed to be balanced by sequestration during regrowth, so carbon dioxide emissions are excluded from reporting. However, if fire incidence increases in extent or intensity due to management or climate change, average carbon stocks will be affected, and this impact must be included
- the formation of charcoal should be included in the estimation of greenhouse impacts of fire: approximately 4%–5% of the carbon consumed by forest fires remains on site as black carbon, which has a turnover time of thousands of years (Forbes et al. 2006).

Climate change is likely to affect the incidence and severity of pest and disease outbreaks in native forests and plantations. Firstly, changes in average or extreme values of climate variables can affect the life cycles of pest populations and the severity of disease. Increased summer temperatures are likely to accelerate the development rate and reproductive potential of insect pests, while warmer winters will increase over-winter survival (Old & Stone 2005). For example, the devastating mountain pine beetle (*Dendroctonus ponderosae*) infestation in the Canadian province of British Columbia, which currently affects 8.7 million ha of forest and is predicted to kill over 800 million cubic metres of pine by 2013, is attributed in part to recent mild winters, which contribute to the high survival of beetle populations over winter (Eng et al. 2006). In southern Australia, increased frequency of extreme wet and dry periods may increase incidence of the root rot pathogen *Phytophthora cinnamomi*. Trees weakened by *P. cinnamoni* have a reduced capacity to survive periods of drought.

Secondly, climate change may extend the geographic distribution of pests and pathogens, affecting forest communities not previously at risk (Cannon 1998).

Thirdly, effects of climate change on the host plant may increase its susceptibility to insect pests and diseases, or its ability to tolerate and recover from herbivory. For example, elevated CO_2 concentration affects the nutritional quality of foliage, largely due to a decline in leaf N concentration (Ainsworth & Long 2005). The resultant change in C:N ratio may result in increased foliage consumption by some species tolerant of low N availability, while others will be inhibited (Old & Stone 2005). It is, therefore, difficult to predict the impact of climate change on defoliation.

In their review of the likely impacts of climate change on pests and pathogens of Australian forests, Old & Stone (2005) concluded that the diversity of Australia’s native forests gives them a strong resistance to pests and pathogens, but that climatic variability due to climate change – particularly an increase in drought frequency – could increase the impact of pest and pathogen attack, thereby compromising the health, and hence the carbon stocks, of Australia’s forests.

The interaction between climate change and the impact of insect pests or fungal pathogens is strongly mediated by the condition of the host tree. Potential increases in crown growth rates, due to increased carbon dioxide or length of growing season, may offset the impact of defoliation; however, slow-growing, stressed trees are less able to recover from defoliation events, and are more vulnerable to secondary damaging agents, such as stem borers. The potential impact of climate change on plantations depends, therefore, on the direct effects of climate change on the population dynamics of the damaging agents, as well as the resultant condition and vigour of the trees. Overall, an increase in extreme weather events is likely to exacerbate the impact of insect pests and fungal pathogens on plantations.

8.5 FISHERIES

Climate change is already affecting Australian marine life and, consequently, Australian fisheries and aquaculture (Newton 2007). However, current climate change research, expertise and knowledge in the fisheries area are, at best, limited and patchy.

The impacts affecting aquatic systems and fisheries (both wild harvest and aquaculture), especially in estuarine and marine areas, are rising sea level, increasing acidity of marine waters, increasing global temperature, and changing rainfall patterns (amount and variability). These impacts have been analysed comprehensively (to the extent permitted by available data) in two recent reviews commissioned by the Australian Greenhouse Office (Hobday et al 2006, Hobday and Matear (eds) 2005); they are summarised in Table 5.

In NSW, the predicted changes in the abovementioned variables will result in alteration of the ocean currents, due to increased frequency of El Niño-Southern Oscillation (ENSO) events, an increase in extreme event storm surges, and a decreasing flow of fresh water to estuaries, with a shift in nutrient supply to the nearshore coastal waters. These alterations will be manifest in significant estuarine and nearshore habitat change, change in trophic (food chain) relationships and shift in the recruitment patterns of aquatic plants and animals, including commercially and recreationally harvested fish and invertebrates. Shifts in the range and distribution of harvested species, the composition and interactions within aquatic communities and the structure and dynamics of communities are predicted to occur.

NSW DPI’s responsibilities under the Fisheries Management Act (FMA) extend beyond the sustainable management of fishing activity, to include conservation of a public resource for the people of NSW. Consequently, the impacts of climate change on natural habitats and biodiversity, threatened species, protected areas and introduced pests are considered alongside the effects on wild fish harvest and aquaculture. Within this range of responsibilities not all impacts are negative.

There are various consequences for exotic species. The impact of species such as the freshwater fish carp may diminish because of reduced spawning opportunities on floodplains. For other exotics, such as the marine alga caulerpa, the distribution may increase, due to more-suitable conditions in estuaries.

Impacts on NSW native biodiversity and threatened species will vary, and will be linked to predicted changes in the principal oceanographic driver on the east coast: the East Australian Current (EAC). Possible species range and distribution extensions of warmer water northern species and constriction in the range and distribution of the cooler water southern species is predicted as the EAC and associated anticyclonic warm core eddy systems move south.

The changing fresh water flow to estuaries and predicted upstream migration of salt water will alter aquatic habitats and change the distribution of wetland plants and aquatic animals. Consequently, the estuary areas suitable for oyster culture will change. The harvest of prawns will also change, as the juvenile stage of their life cycle relies on the upper estuarine wetlands, and migration into the offshore prawn fishery is related to fresh water discharge through the rivers and estuaries. Tidal wetlands lower in the estuaries (particularly saltmarsh), which are also an important nursery habitat, will become smaller, because there is rarely the capacity for them to expand landward as sea level rises.

In Australia, the management of wild harvest fisheries is structured within an ecosystem-based fisheries management (EBFM) framework. As a consequence, risk analysis and adaptive capacity for harvest strategy changes have been incorporated into the environmental impact assessments and fisheries management strategies (FMS) for NSW wild harvest fisheries. Harvest strategy is defined as the variety of fish and invertebrate species that can be taken, the fishing gear/methods permitted for use by licensed fishers, the geographic area in which fishing by an approved method can be carried out, and the statutory management controls and compliance rules that apply to the commercial and recreational fishing industries.

If economic viability is reduced as predicted for impacts resulting from climate change, fisheries resource harvest strategies will affect social wellbeing, often negatively. Harvest strategies change because of changes to the recruitment patterns for fish, crustaceans and molluscs, which occur due to changes in physical habitats and ecological processes in estuaries and the coastal environment. Structural adjustment and adaptive management of fisheries industries may be necessary.

Table 5. Some likely impacts of climate change on Australia’s oceans, coasts and rivers, as exemplified by biophysical change from climate drivers [Australian Greenhouse Office (Hobday and Matear (eds), 2005, Hobday *et al.*, 2006 and Newton 2007), Bureau of

Meteorology (2007), CSIRO (2007), Fisheries Research and Development Corporation (2007), Hennessy *et al.*, (2007) World Wildlife Fund (2007)].

Variable	Impact
Sea level rise and storms	• Rise in sea level due to thermal expansion of the ocean, glacial melt, and increased frequency or intensity of extreme storms, leading to higher risk of inundation and flooding. • Shoreline erosion and realignment, leading to loss of amenity or damage to assets (natural and human).
Warmer ocean temperatures	• Increased frequency of coral bleaching events (present models project the Great Barrier Reef will warm by 2° to 5°C by 2100). • Potential impacts on biodiversity, through effects on the distribution and reproductive patterns of marine organisms and, consequently, food web dynamics (productivity).
Ocean acidification	• Increased CO_2 concentration in sea water is altering ocean chemistry, making it more difficult for calcitic organisms, such as coccolithophores, corals and molluscs, to grow and function.
Decreased rainfall and drought	• Warmer temperatures will cause greater evaporation, increasing the severity of drought for a given decrease in rainfall.
Increased river temperatures (freshwater)	• Warmer temperatures will change species distributions (food web dynamics), as poikilothermic fish and invertebrates attempt to behaviourally thermo-regulate by migrating to cooler water in geographically constrained rivers and lakes. • Metabolic rates increase with the consequent need for more food to support this higher metabolism.
Run-off changes	• Climate changes over land will cause changes in run-off reaching coastal and marine systems, and alter the availability and quality of fresh water – this has implications for productivity and ecosystem function of coastal and estuarine environments. • Related changes in riverine flooding frequency and intensity will occur.
Ocean stability and currents	• Changes to wind and water temperature affect water column stratification and stability, leading to changes in upwelling of nutrient-rich deeper waters and productivity of surface waters. • Changes to ocean currents, notably the East Australian and Leeuwin currents, may affect dispersal and distribution patterns of marine organisms.
ENSO	• Some models suggest global warming may lead to an increase in the frequency or intensity of El Niño events – if so, Australia may have more intense droughts and La Niña floods, particularly in the eastern part of the country.
Tropical cyclones and storm surges	• Combined with higher sea levels, the projected increase in frequency and intensity of tropical cyclones would cause more frequent and intense coastal flooding. • Tropical cyclones may occur further south than they do at present. • There are likely to be shifts in prevailing wind and wave patterns.
Increased fire and wind	• Increased frequency and/or intensity of aeolian dust and fire-borne particulates can affect coastal productivity and promote blooms.

8.6 MINERALS

Climate change is unlikely to have a major direct impact on the mining industry, for which regulations and management strategies are already in place to manage factors such as water usage and environmental issues relating to rehabilitation. While a lack of access to water may affect some mining projects, most mining processes do not generally require potable water. Where high-quality water is required, some mines are already installing desalination units.

Changes in the frequency and intensity of storm events have the potential to impact on mining operations (e.g. tailing dams, sediment and erosion control); however, these impacts can normally be addressed as part of the mine’s water management plan.

The highest risk to the mining industry from climate change is most likely to come from meeting growing community concerns over environmental issues. This is likely to increase the difficultly in obtaining approvals for mining projects (particularly for coal). Additional constraints on mining may also affect the economic viability of individual mines, leading to flow-on effects to communities, through job losses and a decline in regional revenue. Work to develop clean coal technologies may ameliorate this risk to some extent; however, the actual process of mining is likely to face increasing community pressure.

8.7 ADAPTIVE CAPACITY

Costs of climate change

The objective of adaptation is to lower the costs of climate change and in some cases exploit beneficial impacts. An initial focus then concerns the costs of climate change. The costs are highly variable because of both regional differences in the extent of climate change and varying sensitivities of industries to change. Specific climate change effects at an industry level have been discussed in previous sections so a more general discussion is presented here. In the discussion that follows the agricultural sector is used as an example but some of the concepts will also apply to other primary industries.

Modelling studies assuming no adaptation confirm a high degree of spatial variability in the impacts of climate change. Howden and Jones (2004) found that regional wheat production increases in some areas due to climate change, but falls in others. Kokic (2005) reported that in scenarios involving higher temperatures and declining rainfall, wheat production declines in all regions but with substantial declines in some areas (>-20 per cent) and only minor falls (0-5 per cent) in others. While there is some consensus between studies about the variability in regional impacts, the aggregate level of impacts is less clear and is strongly related to the climate scenarios assessed.

An initial starting point in considering the impacts of climate change can be represented by a standard production function. Agricultural production systems use fixed (eg land) and variable inputs (eg labour, fertiliser, seed, irrigation water etc) to produce outputs (eg. wheat yield). A production function quantifies the physical relationship between output and a single variable input with other inputs held constant. In the scenarios discussed below, it is assumed that climate change has a negative effect on agricultural productivity.

Scenario 1 as shown in Figure 15 is an example of the impacts of climate change on an irrigated crop. Assuming that climate change leads to a drier and warmer climate, the production function relating water to crop yield shifts to the right. This implies that crop yield Y_1 can only be maintained if the amount of water applied per hectare increases from X_1 to X_2. Scenario 2 is an example of the impacts of climate change on a dryland crop. All other things being equal, a warmer and drier climate may shift the production function downwards indicating that for a given level of fertiliser input X_1, crop yield falls from Y_1 to Y_2 with climate change.

In either of the above cases, climate change is assumed to decrease the productivity of the variable input being used. In the irrigation case, more water is required to produce the same level of output while in the fertiliser case, a given level of fertiliser input produces less output than before. In the absence of technological changes and adaptations, the optimal level of irrigation water or fertiliser use may change as a consequence. The extent of change not only depends on the physical productivity of inputs but also on the relative prices of inputs and outputs[9].

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[9] Economic theory suggests that producers maximise returns at the point where the Value of Marginal Product (Marginal Physical Product times the output price) derived from the use of an input is just equal to the price of that input.

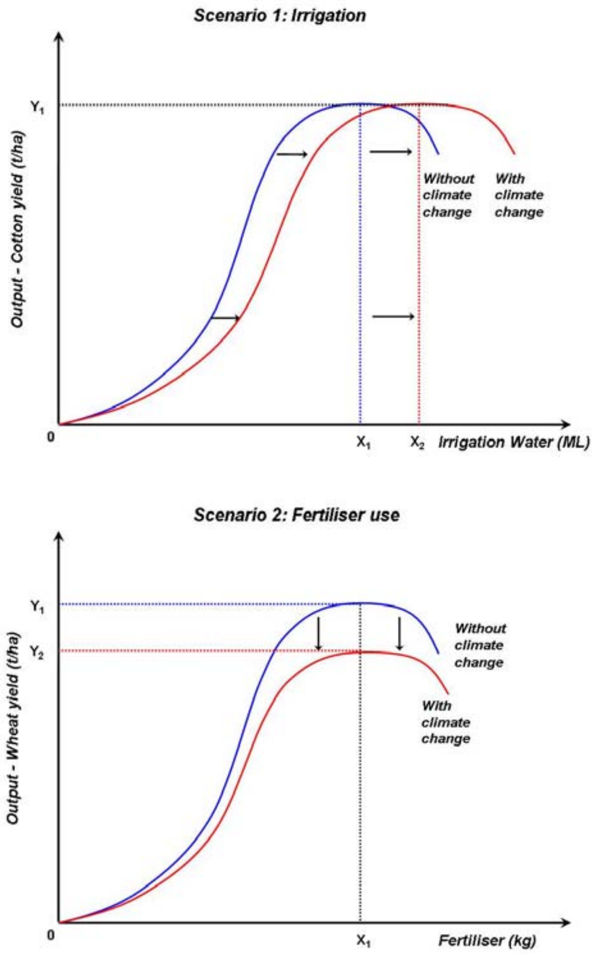

Figure 15: The impact of climate change on production functions

Adaptation to climate change

Specific adaptation strategies and underlying productivity growth may counter the effects like those illustrated in Figure 15 and hence move the production function back towards its original position. In some cases it is possible that a production function post climate change may be preferable to the one which existed pre-climate change. A key research area therefore is to assess how production functions may change under alternative climate change scenarios and the role that different technologies might play in either reducing impacts or exploiting any gains associated with climate change.

Analyses of the direct production effects of climate change is an important area of research but adaptation will be driven by other factors including economic conditions and farm characteristics. The profitability of agriculture in any given region will be influenced by climate change through its affect on the availability and prices of inputs and outputs even if the physical efficiency of agricultural production in that region is unaffected.

Some of the complexities of adaptation become apparent when considering issues like water availability. A drier and warmer climate expected under climate change is likely to lead to reduced runoff and lower average water availability. Greater competition both within and between sectors for reduced water resources will increase water prices and may trigger changes to water use and agricultural production. The scope of possible impacts from climate change in this case is large as is the types of adaptation that could be made In cases like water there is likely to be adaptations occurring both on and off-farm because of strong linkages between agriculture and regional economies. The impacts of climate change will not just be physical impacts on agriculture but rather a complex set of influences that will determine the nature and extent of economic impacts (Kingwell 2006).

A key factor influencing the impact of climate change in primary industries is how well those industries can respond to change. Historically the agricultural sector has shown significant capacity to adjust to variations in both climatic and economic conditions. Adaptations have occurred through the adoption of new technologies, land management practices and farm business strategies.

Some evidence of the success of past adaptations can be found in rates of productivity growth achieved in the agricultural sector. Productivity growth indicates an improvement in efficiency with which inputs (eg land, labour and capital) are converted into outputs (eg crop and livestock products). Over the past 50 years the rate of productivity growth in Australian agriculture has averaged 2.5% per annum (Mullen and Crean 2007). This rate of growth compares favourably to the agricultural sectors in other countries as well as other sectors of the Australian economy.

Capacity to accommodate past change provides some optimism about the agricultural sector's ability to contend with some degree of climate change in the short to medium term. According to Kingwell (2006), 'where climate change is not rapid then farmer's traditional responses to climate variability in broadacre farming is likely to facilitate their effective adaptation to climate change (p.17). However, agricultural systems that have developed to suit current climate variability may not necessarily be well suited to longer term climate change (Kokic et al 2005).

Availability and costs of adaptation to climate change

Previous sections have discussed some of the specific adaptation options in agriculture. Adaptation strategies can be broadly classified as either being of a short or long term nature. Short term options include measures that farmers can quickly adopt and are in the main extensions of measures used to cope with climate variability. They are mainly management related and involve adjustments to the growing season length through changing crop varieties and planting dates, conserving soil moisture through better tillage and grazing practices, and adjusting crop and livestock mix. Longer term options involve various forms of infrastructure investment (erosion control, irrigation efficiency improvements, water storage facilities, specialised tillage equipment) as well as research investments made by R&D organisations into new technologies and crop varieties more suited to a drier and warmer climate (Kokic 2005).

Some issues associated with the merits of adaptation can be discussed through a simple example relating the costs of climate change to temperature increases (see Figure 2). Curve A represents the costs of climate change to agriculture assuming that no adaptation occurs. The curve is shown as having a convex shape based on the proposition by Quiggin and Horowicz (2003) that damages associated with climate change are likely to be a convex function of the rate of warming[10]. In this example small increases in temperature impose only limited costs on agriculture to start with but more substantial temperature rises impose successively higher and higher costs.

Curve B in Figure 2 represents the costs of climate change allowing for adaptation and has a similar shape as curve A. Costs represented by curve B are comprised of those relating to adaptation strategies plus the residual impact of climate change. At low levels of temperature increases there are likely to be adaptation strategies that agricultural industries could implement at relatively low cost. They are also likely to be ones that can implemented in the short term which for broadacre agriculture could involve extension of strategies that deal with climate variability. Howden and Jones (2004) assess the value of two short term adaptation strategies to climate change (changing varieties and altering planting windows) in the Australian wheat industry. They find that with adaptation, climate change has a net positive effect on the wheat industry with the median value of the

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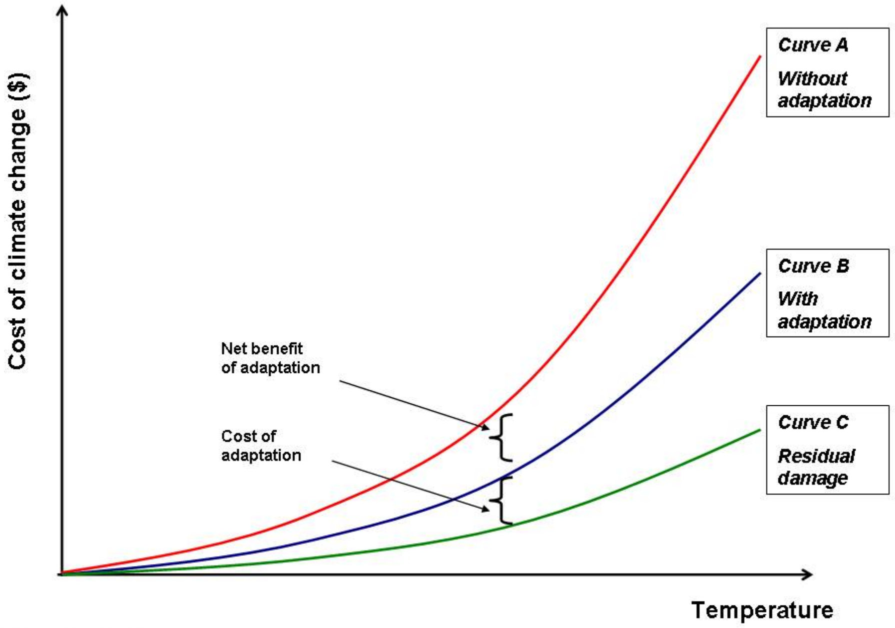
[10] According to Quiggin and Horowicz (p19, 2003) this means 'that the expected damage level is greater than the expected rate of warming'

Australian wheat crop increasing by 5 per cent. Without adaptation, the wheat crop suffered a -0.3 percent decline in value.

As projected temperatures rise, the slope of curve B becomes steeper indicating that while adaptation options are still effective in reducing the costs of climate change, as shown by the gap between curves A and B, the adaptations become more and more costly to implement. These higher cost adaptations are likely to involve longer term changes that require more resources to implement and perhaps involve more fundamental changes to agricultural industries and changes in infrastructure. The shape of this section of curve B will be heavily influenced by the ability of research organisations to develop cost effective technologies that can reduce the impacts of climate change and how quickly these technologies can be adopted by agricultural industries.

Curve C represents residual damage that cannot be addressed through adaptation measures. As temperatures increase, there is a larger residual cost left in absolute terms. For example, improved wheat varieties may reduce the extent of yield decline resulting from climate change but some yield loss is unavoidable. The extent of losses may rise as temperature increases because adaptation options lose their effectiveness in a more and more challenging production environment.



Adapted from Stern (2006)

Figure 16: Example of climate change costs with and without adaptation

Climate change uncertainties

The smoothness in the curves in Figure 1 implies that the underlying rate of climate change is a gradual process and is largely predictable. This is unlikely to be the case because of the stochastic nature of climate and the possibility of abrupt changes occurring in the climate system when particular thresholds are exceeded. It is useful to think about these two issues in the context of the shape of cost curves discussed above.

Climate is stochastic and any climate change is super-imposed on a system that has underlying variability with cyclical fluctuations occurring over various time scales. In addition to ENSO which operates on an inter-annual basis, there are a range of other climate phenomena operating at a wide range of time scales that influence climate variability' (Meinke *et al* 2005). Some of these influence climatic conditions on decadal and inter-decadal time scales. The chaotic nature of climate presents problems for adaptation because there is uncertainty about whether current climate observations are an accurate reflection of longer term climate change. This might be a particular problem for Australia because there is high level of underlying natural variability that acts to mask trends.

One consequence of uncertainty is the likelihood that farmers will make adaptation decisions that are not optimal from an ex-post perspective. Farmers might either over or under invest in adaptation if they act on the basis of observations that do not reflect the longer term climatic state. To the extent that this is true, curve B might be higher than that given in Figure 1 because adaptation is not as efficient as it could be. At the same time, uncertainty about climate change may also influence a farmers' willingness to invest in adaptation because returns from these investments are themselves uncertain.

Uncertainty about the payoffs from adaptation measures may have a large effect on their adoption. Many attributes of a technology influence adoption. Rogers (2005) identifies five key attributes of a technology or innovation that he finds can explain between 49 to 87 per cent of the variance in the adoption of innovations. They include:

- *Relative advantage* - 'the degree to which an innovation is perceived as being better than the idea it supersedes' (Rogers 2005, p.229).
- *Compatibility* - the degree to which an innovation is perceived as consistent with existing values, past experiences and needs.
- *Complexity* - the 'degree to which an innovation is perceived as relatively difficult to understand and use' (Rogers 2003, p 257).
- *Trialability* - the extent to which an innovation can be implemented on a limited basis
- *Observability* - the extent to which the outcomes of an agricultural innovation are visible to others

The stochastic nature of climate is likely to cloud the assessment of innovations based on some of the above criteria. Relative advantage may be more difficult to establish, effects may be less observable and there may be some difficulty in effectively trialling adaptations. All these factors tend to reinforce the importance of uncertainty and the problems it poses for adaptation. Quiggin and Horowicz (2003) argue that there are costs related to uncertainty of climate change, particularly at a local level, which are independent of the damage function.

Innovations that are most likely to be affected by the uncertainty are ones involving long term investment. 'The unpredictability of the location, timing and magnitude of impacts of climate change will impose risk as returns to the investment depend on which state of nature actually eventuates' (Kokic 2005, p.168). In these circumstances it is rational for decision makers to impose a higher 'hurdle' rate for investment returns to reflect uncertainty.

Further, as noted by Kokic (2005), uncertainty about returns means that there is an 'option value' associated with postponing new investment. The potential cost of making a poor decision can be reduced by delaying the decision and waiting for better information about the likely returns from the investment. The returns from investment in adaptation measures therefore needs to meet the standard opportunity cost of capital invested as well as the option value of delaying the decision until better information is available. As a consequence, the uncertainty of climate change is likely to slow down the uptake of adaptation strategies that require long term investment (Kokic 2005).

The possibilities of abrupt changes in climate are also not reflected in Figure 1. One of the major concerns of climate scientists is that the climate may not change gradually, but may reach a tipping point, resulting in a rapid shift in one or more climate variables. An abrupt change in climate is likely to negatively affect the value of some assets. A change could have particularly adverse consequences for production systems that are based on investment cycles of a number of years. For example, pressurised irrigation systems, vineyards and forestry are all long lived assets and are not transportable. In a worst case scenario these assets become redundant while in other cases their effective working life may be reduced. The rate of change in climate is important because it affects the capacity for adaptation whilst also influencing the profitability of adaptation responses (Kingwell 2006). The temporal aspects of climate change are one of the most significant aspects of climate change but one where fundamental uncertainties remain.

The nature of individual farm businesses will also influence the type of adaptation responses adopted. Australian agriculture is generally characterised by a skewed distribution of wealth and farm size, with a small percentage producing the majority of each particular commodity (Kingwell 2006). Generally, the bigger operations have more diversification options at their disposal, which is a positive when responding to the challenges posed by climate change. The most appropriate strategies for the larger organisations are likely to be a combination of spatial diversification and enterprise specialisation within integrated supply chains (Kingwell 2006).

To the extent that there are economies of scale in adjusting to climate change, there may be a furthering of the trend towards larger farms. Smaller farms might find innovative ways of adjusting to climate change but their scope of responses might be more limited to on-farm and local adaptations to climate change. Regardless of the range of adaptation strategies available, it is important that the focus is on increasing the coping range of the particular operation.

Conclusions

Clearly adaptation is a complex area with significant uncertainties given limited information about the extent and rate of climate change as well the dynamic environment in which farmers operate. A slow evolution of climate change is likely to provide sufficient time in which efficient adaptation responses can be developed. More rapid and unexpected climate change will test the adaptive capacity of farmers and the ability of research and development organisations to provide relevant technologies.

The difficulty of discerning cyclical climatic variation from longer term trends creates significant potential for inefficient adaptation. This could involve either over or under investment in climate adaptation technologies in an ex-post sense. More generally, climate change may create additional uncertainties about the returns from agricultural technologies which are affected by climatic conditions. Reduced uptake of technologies may constrain long term productivity growth which has been an important part of the success of Australian agriculture.

Research and development can play a more important role in assisting the agricultural sector to adapt to climate change. Initial research scoping out the likely effects of climate change and feasibility of adaptation options is important in developing strategic areas of longer term research.

9 RESPONDING TO CLIMATE CHANGE

Coal-fired power generation is the largest single contributor to NSW greenhouse gas emissions; therefore, reducing emissions from this sector is critical to achieving substantial emission cuts. Technological methods of controlling emissions, particularly carbon capture and storage, have been proposed.

Agriculture contributes 12% of Australia’s emissions, largely due to methane from ruminant livestock digestion, and nitrous oxide from soils (Figure 17). Methane and nitrous oxide are powerful greenhouse gases, with global warming potential 23 and 296 times (respectively) greater than that of carbon dioxide (IPCC, 2001). Emissions of methane and nitrous oxide represent inefficiency and loss of energy; therefore, reducing these emissions will result in more efficient use of resources. There are a number of strategies that could reduce ruminant methane emissions and emissions from manure. Management of soils in cropping, pastoral and forest systems can reduce nitrous oxide emissions and enhance methane uptake.

Forestry offers potential mitigation through sequestration in growing forests and in wood products, as well as the use of forest biomass for bioenergy.

There is potential for biofuels to reduce emissions from the transport sector.

The opportunities for mitigation of greenhouse gas emissions through actions in the primary industries sector are described in this section.

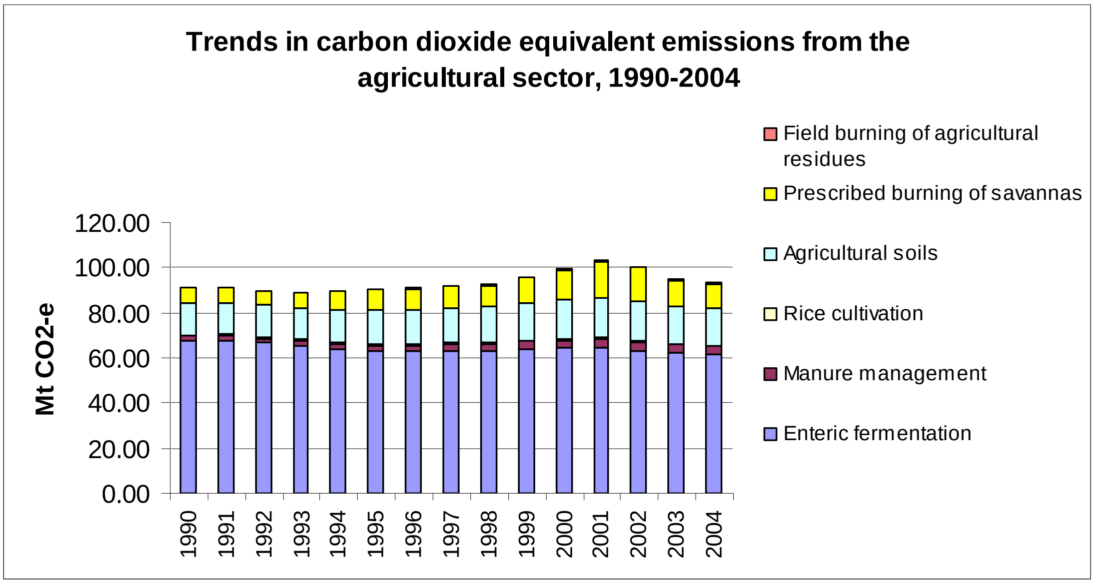


Figure 17. Carbon dioxide equivalent emissions from the agricultural sector (Source: DEH 2006).

In developing policy responses to climate change, it is important to recognise that mitigation actions undertaken through change in land use can impact on other environmental attributes. Some actions are synergistic (e.g. reforestation can sequester carbon, enhance biodiversity and mitigate dryland salinity), but there are inevitably trade-offs between environmental objectives in most land use decisions. Policies that address multiple environmental goals simultaneously will be most efficient and effective in promoting optimal environmental outcomes and sustainable land use (Cowie et al. 2007).

9.1 CARBON CAPTURE AND STORAGE

Carbon capture and storage (CCS) is a potential mitigation measure that, if implemented broadly, could provide huge reductions in GHG emissions from fossil fuel combustion for electricity generation. Potential barriers to implementation include high cost[11], location and capacity of suitable storage sites, and the requirement for long-term monitoring (IPCC 2005). The CCS process requires additional fuel, and produces more carbon dioxide emissions than a similar plant without capture. Using a power generation system that is based on combustion of renewable biomass rather than coal or gas, coupled with CCS, can result in a net removal of carbon dioxide from the atmosphere (Möllersten et al. 2003).

There are four identified options for the storage of CO_2:

- storage in depleted petroleum and gas reservoirs
- injection into deep, uneconomic coal seams

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[11] Carbon capture, transport and storage is predicted to increase electricity cost by 21%–91% for new plants. Retrofitting of existing plants is estimated to double or even triple electricity costs. (IPCC, 2005).

- mineral carbonation
- injection into deep saline aquifers (deep saline water-saturated reservoir rocks).

Storage in depleted petroleum reservoirs

The storage of CO_2 in depleted petroleum and gas reservoirs is the best known and reportedly the least risky of all disposal options. The re-injection of CO_2 into petroleum and/or gas reservoirs has been undertaken as part of enhanced petroleum recovery operations for many years. Petroleum reservoirs, by their very nature, demonstrate that the structure can seal CO_2 within a contained geological structure. However, no suitable sites of this nature have yet been identified in NSW.

Injection into uneconomic coal seams

The injection of CO_2 into coal seams may be feasible as part of an enhanced coal seam methane (CSM) recovery project. Coal seams can absorb CO_2, meaning that this method may achieve permanent disposal, provided the coal is not disturbed by mining and does not have fracture pathways to other formations. Over time, there is evidence that, in some areas, bacteria within the coal seams can convert CO_2 into methane, using the coal as a source of hydrogen. Most coal seams, however, are already saturated with either methane, CO_2 or a combination of both gases. The injection of CO_2 into coal seams could also be used to rapidly displace methane, resulting in enhanced methane recovery.

The total volume of CO_2 that can be stored as part of a coal seam methane project is constrained by limited capacity. In addition, many coal seams already contain significant volumes of naturally occurring CO_2. Potential is further reduced by the fact that a proportion of the CO_2 injected will be released during CSM recovery operations. Furthermore, most of the current CSM projects are extracting gas from coal seams that are likely to be mined in the future, thus releasing the injected CO_2.

Besides these restrictions, there are major technical issues to be overcome, such as the swelling of the coal from the CO_2 injection, which results in reduced permeability, restricting the diffusion of gas across the deposit.

In summary, the disposal of significant volumes of CO_2 into coal seams appears unlikely to play a major role in the sequestration of carbon dioxide in NSW.

Mineral carbonation

Mineral carbonation is a process in which CO_2 is chemically reacted with minerals, such as serpentinite, to produce stable carbonate minerals, effectively locking up the CO_2 permanently. The reaction could occur within an industrial reactor, using mined material, or in situ, by direct injection into serpentinite formations.

NSW Department of Primary Industries advises that:

- there are extensive deposits of serpentinite in Australia
- the Great Serpentine Belt near Tamworth contains significant resources of suitable rocks
- to date, the rate of reaction in the laboratory has been too sluggish or costly to accommodate industrial CO_2 output within industrial reactors
- in situ mineral carbonation would most likely operate at much slower reaction rates. Current research is aimed at increasing the speed of the reaction in industrial reactors
- this technology appears unlikely to prove efficient or effective in the short to medium term.

Injection of carbon dioxide into deep saline aquifers

Disposal into deep saline aquifers involves the injection of CO_2 as a supercritical fluid into suitable geological formations at depths greater than 800 m. This is likely to be the best option, as deep aquifers have the potential to contain enormous volumes of CO_2. It is also likely to be the most suitable disposal option for NSW, as a number of NSW basins are likely to contain deep aquifers.

Exploration and storage potential in NSW

The lack of significant previous petroleum exploration in NSW has resulted in a lack of knowledge of the geology, and hence the storage potential, of NSW basins. The available information suggests that there is potential for geosequestration of carbon dioxide in NSW; however, further work will be required to identify sites that may be suitable for carbon storage.

The identification of suitable sites for sequestration of carbon dioxide, followed by pilot injection projects, is seen as a top priority for NSW.

The scale of any greenhouse benefits will, to a large extent, depend on whether suitable storage sites are identified and, if so, the storage ‘capacity’ of the sites, as well as their proximity to the stationary energy sector’s largest emitters.

9.2 MANAGEMENT OF LIVESTOCK EMISSIONS

Ruminant methane emissions

Methane emissions from ruminant animals, arising through enteric fermentation, comprise 73% of the NSW agriculture sector’s greenhouse gas emissions. Sustained fermentation of feed in the rumen is a normal aspect of the digestive function of ruminants, allowing them to obtain energy and nutrients from cellulosic feed. Methanogenic microbes are the single-cell organisms responsible for methane generation, which represents digested energy going to waste.

The range of livestock management options to reduce enteric methane emissions depends on how effective abatement is defined. There are a large number of strategies that will reduce emissions intensity (i.e. emissions per unit of animal product); put simply, any management choice made to increase reproductive performance or maximise the rate of product generation (liveweight, milk, wool) will lead to a reduction in emissions intensity. Consequently, management practices such as strategic supplementation, feedlot finishing, parasite control and culling of barren females are all potential contributors to reducing the emission intensity of enteric methane. This has been exemplified in the Queensland dairy industry over the past 15 years, as industry consolidation and intensification of production has lowered the methane cost of milk production (Figure 18a) (Howden & Reyenga 1999).

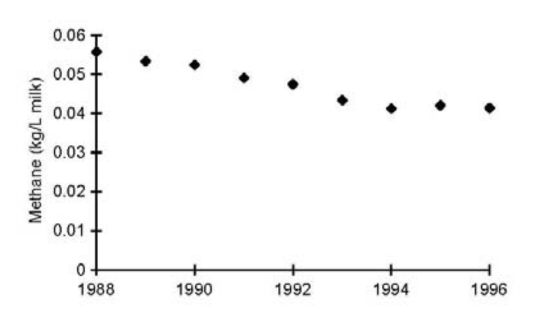

Figure 18a. Decline in emissions intensity (kg/L milk) of enteric methane from the Queensland dairy herd from 1988–1996 due

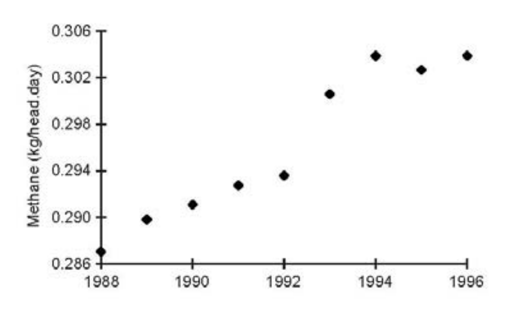

Figure 18b. Rise in average daily enteric methane emission from Queensland dairy cows from 1998–1996 associated with

to intensification and improved management (Howden & Reyenga 1999).

intensification and improved management (Howden & Reyenga 1999).

Similarly, system modelling has shown that sowing improved pasture and stocking sustainably can enable lamb enterprises to generate more profit while using less land for grazing and emitting less methane (Alcock & Hegarty 2006). It should be noted that, while emissions intensity is reduced by improved management, daily emissions of methane per animal may in some cases be increased (Figure 18b); therefore, total emissions may increase.

If the mitigation goal is reducing total emissions per day, practical mitigation options are far fewer, and can be summarised as follows.

Reduction in livestock numbers

This is not popular with the rural sector, and can only be made revenue-neutral or financially advantageous if the productivity of the remaining animals is improved.

Changing diet type from a roughage to a cereal-grain base

While high starch (grain) diets do reduce methane emissions relative to an equal weight of cellulose (roughage – Figure 19), the capacity for cattle to eat is often higher in feedlots than when grazing. It should also be remembered that the carbon cost of grain production is far higher than that of pasture. This may need to be considered if life cycle emissions accounting is adopted by agriculture. In a comparison of life cycle emissions from grazing versus fully fed dairy cattle in New Zealand, Van Der Nagel et al. (2003) calculated that a 250-cow herd on pasture would produce 772 t CO_2-e per annum, while the same herd fed a mixed ration of cut forage and concentrates produced 2765 t CO_2-e per annum. The difference was largely a consequence of soil carbon loss incurred in providing the mixed ration. Life cycle assessments of diets used in beef feedlots have yet to be made.

Genetic improvement of cattle

Cattle selected for improved net (or residual) feed efficiency eat less feed than cohorts growing at the same rate, and so produce less methane (Nkrumah et al. 2006; Hegarty et al. 2007). Recent modelling suggests that selection of bulls for this trait within the Australian beef industry will reduce enteric methane emission by over 550 000 t by 2026 (Alford et al. 2006). Additionally, dairy cattle in NZ bred from European cattle produced more methane per unit feed intake in early lactation than the locally bred lines, suggesting scope for genetic selection (Robertson & Waghorn 2002).

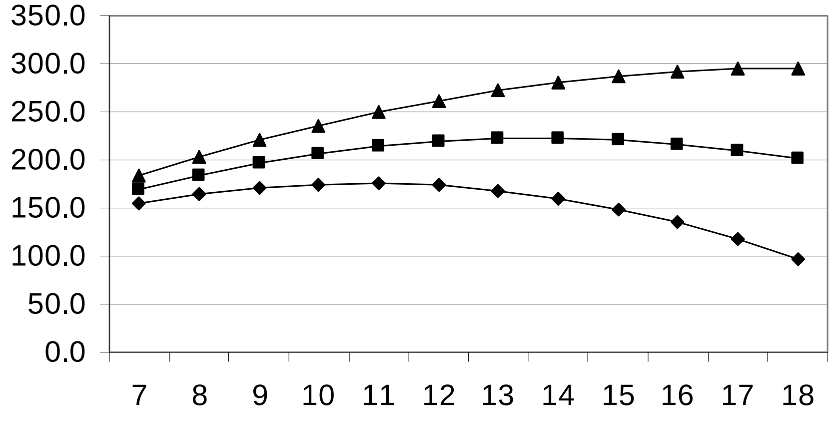

Figure 19. Cattle on feedlot diets (~12 MJ/kg DM) can be expected to produce less methane per day than cattle on low-quality pasture (8MJ/kg DM). Chart shows daily methane production (g/d ; as predicted by Blaxter & Clapperton (1965) of a steer consuming 7–18 kg of diets containing 8(▲), 10(¦) or 12(♦) MJ of metabolisable energy /kg DM.

Targeted manipulations of the rumen ecology

There are two strategies being developed to induce low-methane fermentations in livestock.

1. Dietary additives of short-term effect: There are a number of existing agents available for this purpose, including dietary oils (especially coconut oil), tannins (extracted from a range of sources) and monensin$^{®}$. The long-term efficacy of these agents has not been established, and in the case of coconut oil and propionate precursors, cost may be prohibitive.
2. Agents achieving long-term rumen ecological change: None are yet available, but possible strategies being researched include vaccines against rumen methanogens, agents to eliminate rumen ciliate protozoans, and microbial reductive acetogenesis activated in the rumen by probiotic or chemical means.

In summary, while livestock emissions constitute 13% of Australia's total greenhouse gas emissions, current practical options to reduce annual emissions without compromising livestock numbers and profitability are few, and a commitment to ongoing development is required. The livestock sector will have maximum flexibility to improve greenhouse efficiency if emissions are defined, not as Gg/year, but in relation to animal productivity (gG/t product) describing emissions intensity.

Management of emissions from manure

Though emissions from manure are a relatively small component of the overall greenhouse gas emissions profile, there are some opportunities for mitigation in manure mangement. The opportunities are greatest in management of feedlot, piggery and poultry manure, through collection and beneficial use of methane emitted from fermentation. Collected methane may be flared, or used beneficially as an energy source.

9.3 SOIL CARBON MANAGEMENT

The importance of soil organic carbon as a significant carbon sink is being increasingly recognised in climate change mitigation strategies. Soil contains huge quantities of carbon – generally around 50–300 t per ha, equivalent to 180–1100 t CO_2-e. In comparison, above-ground biomass of pastures and crops usually contains 2–20 t C per ha, while plantation forests can accumulate 250 t C per ha. Globally, the soil carbon pool is estimated to hold 2000 Gt of carbon, compared with 500 Gt carbon in vegetation (Watson et al. 2000).

Soil organic carbon is derived from plant inputs, especially leaves and fine roots, and plays a fundamental role in the global carbon cycle. The stock of carbon in a soil reflects the balance between the inputs from plant residues and losses due to decomposition, erosion and leaching.

Intensively cropped soils have low organic carbon content, due to disturbance, erosion and regular periods of minimal organic matter input during fallow and in the early stages of crop growth. A change in land use from forest or grassland to cropping will, therefore, generally lead to a loss of 50% or more soil carbon (Guo & Gifford 2003). Australia's cropping soils have lost a substantial amount of C (estimated at 1050 Mt) following the introduction of intensive cropping (Swift & Skjemstad 1998); thus, there is significant potential to increase C stocks in these carbon-poor soils by adopting improved land management practices. Small increases in soil C over large areas can significantly mitigate the rising atmospheric concentration of carbon dioxide. Furthermore, in addition to mitigation of greenhouse gas emissions, increasing soil organic matter has a positive impact on soil health, productivity and resilience (Bhupinderpal-Singh et al. 2004; Bhupinderpal-Singh & Rengel 2006; Tisdall & Oades, 1982; Sherwood and Uphoff, 2000).

Organic matter in soil is made up of several discrete pools, which decompose or accumulate at different rates (Buyanovsky et al. 1994; Conteh et al. 1998; Wang et al. 2004). The most labile pool has a rapid turnover rate of 1–5 years, while the most recalcitrant pool, comprised predominantly of charcoal, has a turnover time of tens of thousands of years (Parton et al. 1987). Soil C stock increases in the labile pool are vulnerable to future loss; it is desirable to fix atmospheric C into recalcitrant soil organic matter pools, because of their slower turnover rate.

Management practices that can increase soil organic carbon stocks include:

- retention of forest slash and crop residues, rather than burning them, to increase organic matter input and protect against erosion of the carbon-rich surface soil (Rasmussen & Parton, 1994; Ayanaba et al. 1976). The effective control of diseases harboured by crop residues needs to be considered when this practice is adopted
- application of fertiliser, to overcome nutrient deficiencies, thereby enhancing plant growth and, consequently, litter inputs (Johnson 1992; Schroeder 1991; Turner & Lambert 1986; Dalal & Chan 2001). Fertiliser rates and timing should be matched to the requirements of the crop/forest, to maximise efficiency of fertiliser use and limit leaching and runoff. It should be noted, however, that greenhouse gases are emitted in the manufacture of fertiliser, particularly nitrogen fertilisers (Wood & Cowie 2004), and application of nitrogen fertilisers can cause nitrous oxide emissions (Boeckx & Van Cleemput 2001). These emissions should, therefore, be balanced against the soil carbon gain
- application of organic amendments. Recycled organics, such as manures, biosolids, composts and char are likely to be more effective than fresh plant residues in raising soil C, because the carbon is present in relatively more recalcitrant forms (Zinati et al. 2001; Lehmann et al. 2006)
- selection of cropping, forest or pasture systems to maximise plant growth. Each species has a different carbon allocation strategy that results in a different pattern, rate, quality and quantity of organic carbon input to the soil. Mixed-species planting can maximize biomass production where species have facilitative, rather than competitive, interaction; mixtures including nitrogen-fixing species – e.g. acacia with eucalypts (Bauhus et al. 2000), lupin with pine (Beets & Madgwick 1988), and clover with pasture grasses (Ledgard 1991) – commonly produce higher total biomass yields than monocultures of either species. In cropping systems, organic input can be maximised by minimising fallow and implementing opportunity cropping
- minimisation of cultivation disturbance, to reduce mineralisation and erosion losses. Minimising soil disturbance will conserve soil carbon, particularly on erodible soils. Internationally, reduced- or zero-tillage planting techniques increase soil carbon in many cropping systems (e.g. Lal 1997; Alvarez 2005; Puget & Lal 2005); however, in Australia, positive impact of minimum tillage on soil carbon has only been found in wetter temperate regions (Dalal & Chan 2001; Heenan et al. 1995; 2004). Site preparation for tree planting commonly involves ripping, often in conjunction with mounding. It may be possible to reduce disturbance without jeopardising growth rate in some soil types. Longer rotations, or coppicing, reduce the frequency of soil disturbance in forest systems, and so promote soil carbon
- modification of grazing management to maintain pasture cover, thereby minimising erosion losses, and maximising organic input to soil.

Many studies conducted in Europe and USA (which have predominantly cool climates) have shown that soil organic C content tends towards a new equilibrium within 20–30 years after a change in management, such as from conventional tillage to no-till (West and Post 2002; Alvarez 2005); however, studies conducted in Australia and Asia (in climates ranging from subtropical/tropical to semi-arid/arid conditions) indicate that longer periods are required (Heenan et al. 1995; 2004; Wang et al. 2004; Yadvinder-Singh et al. 2005). This inconsistency in the rate of soil C stabilisation probably results from the interacting effects of climate, local edaphic conditions and crop management on the rate of plant growth and heterotrophic respiration (Franzluebbers & Steiner 2002; Chan et al. 2003; Wang et al. 2004; Alvarez 2005). Long-term studies are critical for determining the impact of farming practices on the dynamics of soil organic matter and associated soil properties (Chan et al. 2003).

Land use and management practices that sequester soil carbon can impact on emissions of the greenhouse gases N_2O and CH_4, and the interactions between these gases and carbon balance can be complex (Tang et al. 2006). For example, applying nitrogen-based inorganic fertilizers and/or organic amendments to enhance plant growth may lead to carbon sequestration in vegetation and soil; however, such benefits could be partially or completely offset by increased emissions of N_2O (Dalal et al. 2003). In addition, higher rates of N application may suppress oxidation of CH_4 by soil methanotrophs, especially in aerobic soils (Bodelier & Laanbroek 2004), further reducing the net mitigation benefit.

In general, CH_4 oxidation rates are greater in forest soils than in tilled agricultural soils (Suwanwaree & Robertson 2005); however, disturbance during site preparation and harvesting/logging operations may accelerate mineralisation of soil organic matter and release of inorganic N, and inhibit methanotrophic activity (Hütsch 1998; Pu et al. 2001). This may temporarily convert plantation lands into a significant source of carbon dioxide and N_2O, and may reduce the CH_4 sink capacity of soil. These complex interactions must be considered in accounting for the net greenhouse impact of mitigation practices in agriculture and forestry.

Although soil carbon management in agricultural systems is not currently recognised as an eligible offset under the NSW Greenhouse Gas Abatement Scheme, it may be included in the proposed National Emissions Trading Scheme (see Section 9.10). Inclusion of soil carbon management in any future emissions trading scheme will depend on the development of cost-effective methods for estimating soil C change under changed land management practices.

9.4 MANAGEMENT OF FOREST AND AGRICULTURAL SOIL EMISSIONS

Soils can be a significant source of nitrous oxide, under both anaerobic and aerobic conditions, mainly through denitrification (Ambus et al. 2006). Nitrogen fertilisers, biological nitrogen fixation by legume species, and the urine and dung of grazing animals are all sources of nitrous oxide emissions. Very few studies of nitrous oxide emissions have been undertaken in Australia (Dalal et al. 2003); however, recent studies by the CRC for Greenhouse Accounting have measured N_2O emissions from wheat in Victoria and WA, irrigated pasture in Victoria, and irrigated cotton and maize in NSW (e.g. Barker-Reid et al. 2005; Phillips et al. 2006; Wang et al. 2006), to investigate drivers of N_2O emissions in agro-ecosystems (Galbally et al. 2006).

Available estimates of nitrous oxide emissions are highly variable. Until recently, the estimates of nitrous oxide and methane emissions included in Australia’s inventory were calculated using general default emissions factors. The abovementioned research by the CRC for Greenhouse Accounting, on which Australia’s inventory is now based, determined that for dryland cropping the nitrous oxide emissions from applied fertiliser were an order of magnitude lower than the IPCC default value, though emissions from irrigated crops and pastures were several times greater than the default. Accurate data on nitrous oxide emissions from soil are required to devise appropriate global mitigation and adaptation policies.

Similarly, very few studies have measured rates of methane exchange from soils in Australia (Simpson 2005). Globally, soils are an important sink for methane, and can consume about 5% of the annual load of methane to the atmosphere (IPCC 2001b). Aerobic, well-drained soils are usually a sink for methane, due to the high rate of methane diffusion into such soils and its subsequent oxidation by methanotrophic microorganisms

(Simpson 2005). In contrast, large emissions of methane are common where anaerobic conditions are favoured (e.g. wetlands, rice paddies and landfills), due to high activity of methanogenic microorganisms in these environments (Conrad 1989). Reforestation of pasture lands and associated silvicultural practices, such as site preparation, N-fertilisation and burning of slash, have the potential to significantly alter the rates of mineralisation and nitrification of soil organic matter, as well as carbon dioxide, nitrous oxide and methane fluxes from soil (Dalal et al. 2003; Tang et al. 2006).

9.5 REFORESTATION

Reforestation can contribute to the mitigation of greenhouse gas emissions through sequestration of carbon from the atmosphere. A forest sequesters carbon until it reaches maturity, after which carbon stock remains essentially constant, unless the forest is disturbed (e.g. by harvest or fire). The sequestration rate of planted forests depends on climate, soil factors and forest management (i.e. planting configuration, species, stocking rate, establishment methods, fertiliser and weed control).

Forests NSW has developed accurate models of sequestration for its major plantation species, which are used in carbon accounting under the NSW Greenhouse Gas Abatement Scheme. The Carbon Sequestration Predictor – a simple software tool produced by the former State Forests, NSW Agriculture and Department of Land and Water Conservation, with the CRC for Greenhouse Accounting – gives estimates of potential sequestration for a range of reforestation types for different rainfall regimes and soil types (Montagu et al. 2003). This tool is specifically developed for lower rainfall regions of NSW (< 800 mm) where few data are available.

The AGO's greenhouse accounting model, FullCAM (Richards 2001) – distributed as NCAT, the National Carbon Accounting Toolbox[12] – is a sophisticated modelling tool, used to quantify Australia's emissions profile for the agriculture, forestry and land use change sector. NCAT can be used to estimate carbon sequestration potential at specific sites.

The annual sequestration rate over the growth phase usually ranges from 8–25 t CO_2-e.ha^{-1}. A commercial hardwood plantation on the NSW North Coast is likely to sequester 600–1000 t CO_2-e.ha^{-1} by the time it reaches rotation age. The average carbon stock over several rotations, representing the long term net mitigation benefit of the plantation, is about 300–500 t CO_2-e.ha^{-1}.

Besides the carbon stock in forest biomass, the dynamics of the soil carbon pool influence the mitigation impact of reforestation. Conversion of cropland to forest is likely to increase soil carbon; from their meta-analysis of published literature, Guo and Gifford (2002) concluded that, on average, reforestation of cropland increases soil C stock by 18%–20%. Conversion from pasture to forest is likely to initially decrease soil C stock, as a result of a decline in pasture litter inputs in the early phase of plantation establishment; this is especially true of fertile pastures with a high proportion of labile soil carbon. As the plantation grows, soil carbon is replenished from litter fall and root turnover. In broadleaf forest species, soil C is generally restored to the original stock within 30 years. In contrast, evidence suggests that reforestation with pine species generally leads to around a 15% decline in soil carbon stock; however, this conclusion is based on limited data, and so needs to be verified (Guo & Gifford 2002; Paul et al. 2002).

There is considerable uncertainty regarding modelled predictions of carbon sequestration, particularly with respect to the soil carbon pool. This uncertainty will be reduced by research that measures the actual rates of sequestration, and produces data that can be used to improve prediction models. Due to impacts of temporal and spatial climate variability, spatial heterogeneity in edaphic factors, and variable incidence of pests, disease and fire, there will always be uncertainty in estimating the sequestration potential of forests.

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[12] Available from the Australian Greenhouse Office http://www.greenhouse.gov.au/ncas/ncat/index.html

Besides climate change mitigation, further potential environmental benefits of reforestation include enhancement of biodiversity, improvement of stream water quality through reduction in nutrient runoff and soil erosion, and mitigation of dryland salinity. Strategically siting reforestation in areas of high salt export can reduce stream salinity (e.g. Ellis et al. 2006).

9.6 ROLE OF FOREST PRODUCTS

It has been increasingly acknowledged that wood products can significantly extend the carbon sequestration benefits provided by forests (Skog & Nicholson 1998; UNFCCC 2003). In addition to the physical storage of carbon in wood products (both in service and in landfills), further greenhouse benefits can be obtained through the use of processing residues to generate energy in lieu of fossil fuels, and through the use of wood products instead of more energy-intensive materials (Ximenes 2006). Wood products play an important role in Australia's carbon balance. The accumulated carbon stock in wood products in Australia (in service and in landfills) is approximately 230 million tonnes of carbon (AGO 2007c), which is equivalent to approximately 1.5 times Australia's annual greenhouse gas emissions.

New South Wales is the main producer of both sawn softwood (790 000 m^3) and sawn hardwood (316 000 m^3) in Australia (ABARE 2005). Approximately 75% of the sawn timber is used for residential purposes (BIS-Shrapnel 2000), with about 80% of the sawn pine used for framing applications in houses, and approximately 50% of the sawn hardwood used as sub-flooring and fencing (Ximenes 2005). Depending on the type of product manufactured and the disposal method used at the end of its service life, the carbon will remain 'locked up' in the product for many decades (e.g. Gardner et al. 2002; Figure 20).

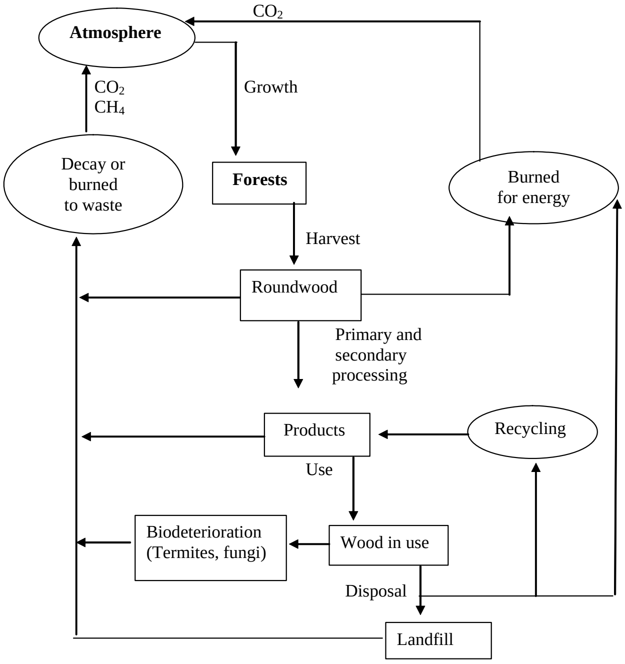

Figure 20. Life cycle of carbon in wood products.

Research by the CRC for Greenhouse Accounting suggested that up to 70% of the carbon in harvested logs can be considered to be permanently stored – either directly in the wood products (including storage in landfill after disposal of redundant products) or through use for bioenergy (displacing emissions from fossil fuels). Thus, for a plantation with carbon stock at harvest of 375 t CO_2-e.ha^{-1}, 300 t CO_2-e.ha^{-1} would be in the above-ground components, including 250 t CO_2-e.ha^{-1} in the stem. Of this latter amount, 175 t CO_2-e.ha^{-1}

would be permanently stored at each harvest. After three rotations, the value of carbon stored in wood products or through avoided fossil fuel use would be 525 t CO_2-e.ha^{-1}, compared with the carbon storage in the forest of 375 CO_2-e.ha^{-1}.

9.7 PLANT BREEDING

Perennial grasses

NSW lacks persistent improved grasses in low rainfall areas. A more comprehensive suite of grasses is needed to cope with increasing climate variability, as well as predicted declines in rainfall in many of our agricultural regions. Native grasses have promise, but experience problems with seed harvesting and establishment, which species such as phalaris, cocksfoot and fescue do not. There is significant potential to extend the drought-tolerant fescue, cocksfoot and phalaris breeding programs through accessing and improving Hispanic and Moroccan summer-dormant germ plasm. A renewed commitment for continuation of tall fescue and cocksfoot breeding for medium to low rainfall areas is required. Despite a substantial evaluation effort over the past 15 years, a range of accessions from the Mediterranean still remain to be screened. There are also a number of molecular breeding opportunities, particularly for tall fescue.

For temperate grasses, periodic drought and encroaching climate warming will increasingly threaten plant persistence. It is therefore necessary to investigate the mechanisms and strategies of drought response in prominent improved grasses, such as tall fescue, and to identify adaptive metabolic processes which might be exploited in plant breeding for persistence. The focus should be on water-soluble carbohydrates, particularly fructans. Fructans are the major form of stored carbohydrate in many C3 grasses, including tall fescue. An important role of fructan synthesis in C3 grasses may be to regulate osmotic potential during moisture stress. In addition, water-soluble carbohydrate reserves are considered to be a primary source of carbon for regrowth after defoliation, or when a stress is relieved. The accumulation of high molecular weight fructans in tiller bases has been positively correlated with drought survival and after-drought regrowth in perennial ryegrass in Mediterranean environments. Water-soluble carbohydrates and fructans in tall fescue have not been fully researched in Australia. A better understanding of their influence on drought tolerance will bring about the potential to select tall fescue material with superior persistence and production to existing cultivars for lower rainfall areas. If the traits associated with increased drought tolerance are under the control of major genes, this would provide the potential for marker-assisted selection for persistence. The objective of this work will be to examine the role of water-soluble carbohydrates and fructans in tall fescue drought survival, by comparing a diverse germ plasm collection that is likely to exhibit different drought-response strategies.

For tropical grasses, there is considerable potential for improvement of the cool season performance of a number of species, not only for the NSW slopes and plains, but also for marginal tablelands country. The tropicals will have a number of advantages if the trend to hotter, drier weather continues, as they can grow at higher temperatures, and are very deep rooted, allowing them to access water. There are, however, some management issues, such as establishment, companion legumes and quality. With regard to molecular breeding, there may be potential to identify markers which will eventually be used to improve the frost tolerance and adaptive potential of tropical grasses in NSW.

9.8 BIOENERGY OPTIONS

Energy production and consumption releases large quantities of carbon dioxide. Australia’s consumption of energy has more than doubled between 1974 and 2004 (from 2695 PJ to 5525 PJ). Per capita, Australia is one of the largest consumers of primary energy, ranked ninth in the world (ABARE 2005), with current growth in energy consumption around 1.9% per annum (ABARE 2006). Australia is a net energy exporter, with the total energy produced in Australia during 2004–05 estimated at 17 524 PJ (ABS 2006). Coal accounted for just over half of Australia's energy production (8765 PJ).

Renewable energy accounted for around 5% of Australia's total stationary energy production in 2004–05 (265 PJ) (ABARE 2006). Biomass is the major source of renewable stationary energy, most of which is utilised in sugar mills and saw mills to provide heat.

Hydro is the largest source of renewable electrical energy in Australia, but growth of renewable capacity is currently focused on wind and biomass sources in particular (ABARE 2006). Within NSW, approximately 90% of electricity is currently generated from coal, but a mandatory target of 15% renewable electricity by 2020 has recently been adopted (DEUS 2006). Electricity generation from biomass could contribute to this target, but significant market and technological development is required to meet this opportunity. NSW experience in biomass energy applications includes installation of high-efficiency boilers in sugar mills to generate electricity from bagasse, and demonstration of co-firing coal with wood waste at several large coal-fired power stations.

Biomass for combustion applications can be supplied from harvest and processing residues from forest and agricultural industries, as well as from purpose-grown crops. A similar range of potential biomass feedstocks could be utilised to produce liquid biofuels.

The most common biofuels are ethanol (produced by fermentation from sugar and starch crops) and biodiesel (produced from waste cooking oil, tallow and oilseed crops). Production of ethanol from ligno-cellulosic feedstocks has not been economically viable to date, but recent developments have greatly improved prospects for this technology. The increased cost of fossil fuels for transport, as well as environmental concerns (including health and climate change) and concerns for the security of energy supply, have increased interest in biofuels. In 2004/05, NSW consumed 6250 ML of petrol and 3450 ML of diesel[13]. The NSW Government has established a task force to investigate the opportunities and issues associated with mandating a 10% ethanol blend. A 2% volumetric mandate came into force in September 2007, and the task force will further consider the implications of increasing the mandate to 10% by 2011. Some basic considerations for agriculture in meeting the demand generated by this mandate include:

- capacity to produce feedstock
- sustainability and resilience of production systems
- energy balance of production systems
- impact of new markets on existing industries (e.g. grain use by intensive industries)
- development of technology for 'second generation' biofuel systems that will deliver greater energy efficiency and greenhouse gas mitigation, and will not compete directly with food supplies.

Significant research and policy work is required to ensure that bioenergy systems deliver substantial greenhouse gas mitigation impacts. Confirmation of beneficial greenhouse outcomes will increase consumer acceptance, thereby increasing market potential.

The benefit of a bioenergy system is sometimes expressed in terms of energy output relative to energy input, or greenhouse gas emissions per unit energy output; however, the most appropriate measure of greenhouse mitigation benefit is the emissions reduction of the bioenergy system with respect to the fossil fuel system that is displaced (Schlamadinger et al. 1997). The benefit depends on the feedstock (e.g. use of wood residues or wastes from processing yields more positive greenhouse and energy balance outcomes than use of purpose-grown crops), and the energy conversion process (e.g. fermentation, pyrolysis, gasification). Various studies have calculated a wide range of values, ranging from low (and even negative) mitigation benefit, through to strong, positive values. For example, Pimentel (2001) argues that there is more energy consumed than produced in production of ethanol from maize in the USA. This is rebutted by Graboski & McClelland (2002) and

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[13] http://www.abareconomics.com/interactive/energy/index.html

Hill et al. (2006). Much of the variation is due to inconsistent application of life cycle assessment (LCA) methodology; the analysis is strongly influenced by determination of the system boundaries. LCA should be conducted in accordance with the International Standards Organisation series 14040 (Life Cycle Analysis). Specific guidance on the application of the life cycle approach to calculating greenhouse gas balance for bioenergy systems is available from Schlamadinger et al. (1997). To allow for comparison of the respective fossil and biofuel systems, it is important that ‘upstream’ emissions are included.

Upstream (or pre-combustion) emissions are produced during:

- extraction of fuel (e.g. removal from oil fields)
- production of fuel (e.g. cultivation and harvest of biomass)
- transport of crude oil/biomass to respective conversion facility (e.g. by ship, rail, road or pipeline)
- processing and conversion of oil/biomass to a finished fuel (e.g. with energy from coal, gas or co-generation)
- distribution of fuel to retail stations or bulk wholesale uses.

There are few detailed LCA reports available for Australian bioenergy systems. The most comprehensive work on biofuels in Australia has been undertaken by CSIRO (Beer et al. 2001, 2004). There is a clear need for Australian research to assess the performance of bioenergy systems under local conditions and agronomic systems.

Generally, the production of biofuels from annual crops (e.g. corn, wheat, sugarcane), with associated high intensity of production, will have a marginal environmental benefit compared with biofuel production from woody and grass (ligno-cellulosic) production systems, which have higher efficiency and energy yields. Reported net energy balance for corn to ethanol usually shows that around 10%–25% more energy is produced than is invested (IEA 2007); for biodiesel from oilseeds this figure is 70%–90% (Hill et al. 2006), while for ligno-cellulosics a range from 200% to over 600% has been suggested (Farrell et al. 2006). An additional advantage of bioenergy systems based on woody crops is that they are less susceptible to yield fluctuations due to climate variability.

Significant research is still required to develop an understanding of the optimal biomass production systems (e.g. which product from which crops), as well as how the systems compare in terms of greenhouse gas mitigation. The LCA process helps to systematically identify areas in which research is required to meet the objectives of sustainable production systems; however, there is significant work required to develop the science and policies to support this process, and assure consumers that the biofuel they use is benefiting the environment in relation to air quality, energy balance, greenhouse gas emissions and production system sustainability.

9.9 POLICY RESPONSE

International policy response

In the 1980s, several research groups around the world produced projections of the effect on climate of increased carbon dioxide in the atmosphere, and the possible impacts on agriculture, forests and ecosystems. In response, the World Meteorological Organisation and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The panel’s role is to provide comprehensive and transparent assessment of climate change, based on the best available scientific, technical and socioeconomic information. The panel draws on work by thousands of specialists from over 100 countries around the world.

The IPCC has issued four major assessment reports (1990, 1996, 2001 and 2007), describing the current state of knowledge of climate science, future projections and potential for mitigation. The IPCC also produces methodology reports, providing guidelines for greenhouse gas reporting, used by parties to the United Nations Framework Convention on Climate Change (UNFCCC – see below) in the preparation of national inventories. In addition, the IPCC produces special reports and technical papers on specific topics.

Recognising the serious threat posed by climate change and the need for global action to tackle the threat, the UNFCCC was agreed in 1992. The aim of the convention is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the Earth's climate system. Parties agreed to implement programs to reduce greenhouse gas emissions, and to report annual inventories of emissions. Recognising that stronger action was urgently required, the commitments of parties were strengthened through the adoption, in 1997, of the Kyoto Protocol, under which industrialised countries (those listed under the Protocol's Annex 1) committed to individual, legally binding targets.

The targets agreed by the industrialised countries deliver an average 5% emissions reduction (compared with 1990 levels) by 2012, though targets differ between parties; Australia negotiated a target to restrict emissions to 108% of 1990 levels. Developing countries do not have targets for emissions reduction under the present agreement.

Currently, 168 countries have ratified the Protocol, covering approximately 61.6% of world emissions (UNFCCC 2006a). Notable omissions include Australia and the United States of America (both countries have signed the Protocol, but it is the ratification process that makes it legally binding.) Although Australia has not ratified the Protocol, the Commonwealth Government has expressed the intention to meet the 108% target, and current projections indicate emissions of 109% compared with 1990 during the commitment period (2008–2012) (AGO, 2006b). The Protocol addresses emissions of six greenhouse gases: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons and hydrofluorocarbons. Aspects of the Kyoto Protocol that are relevant to primary industries include:

- Article 3.3, which allows certain forestry activities – afforestation and reforestation since 1990 on land that was cleared prior to 31 December 1989– to be considered towards a party's emissions reduction commitments. The growth increment of eligible forests during the commitment period (2008–2012) creates 'removal units', which can offset an equivalent amount of fossil fuel emissions. Reductions in carbon stock that occur during the commitment period as a result of post-1990 deforestation are counted as an emission
- Article 3.4, which allows parties the option of including in their accounting additional sequestration in plants and soil, through management of cropland, grazing land and existing forests, as well as revegetation. Australia has agreed to a zero cap on credits from forest management, and to exclude all 'Article 3.4 activities' from accounting
- Article 3.7, which states that for parties for which land use change and forestry was a net source of greenhouse gas emissions in 1990, the emissions from land use change can be included in calculating the 1990 baseline. Because this clause applies to Australia, the emissions from deforestation in 1990 are included in Australia's baseline
- Article 6, which allows an Annex 1 party to implement emissions reduction projects in another Annex 1 country, and count the resulting 'emission reduction units' against its own target. This is known as the 'joint implementation' mechanism
- Article 12, which defines the clean development mechanism, through which parties to the Protocol can obtain 'certified emission reductions' from emissions reduction projects implemented in non-Annex 1 (developing) countries
- Article 17, which allows for emission trading between parties that have ratified the Protocol.

The parties to the Protocol have agreed that a second commitment period should commence after 2012. Details of targets and the accounting framework for the second commitment period will be negotiated over the next few years.

The features of the Kyoto Protocol – including the accounting framework and rules governing the inclusion of sequestration activities and methods for estimation of emissions and removals – have had and will continue to have a strong influence over NSW policies and future emission trading schemes. It is likely that some of these details will be revised for the new commitment period. It is important that Australian policies are compatible with international initiatives developed under the UNFCCC and Kyoto Protocol, so that Australia has the option to participate in future.

There is growing consensus that it is critical to stabilise atmospheric carbon dioxide at 550 ppm or less, to avoid catastrophic impacts. At 550 ppm, global average temperature is predicted to rise by 2°C. To achieve stabilisation at 550 ppm will require the developed countries to reduce their emissions to 60% below 1990 levels by 2050. This aspiration is beginning to be reflected in policy development in some jurisdictions, in Australia and internationally.

Asia-Pacific Partnership

The Australian Government, along with the United States of America, initiated the Asia-Pacific Partnership on Clean Development and Climate, known as AP6.

The six-country partnership – which also includes China, Japan, India and Korea – brings together major emitters among the developed and developing countries, in recognition of the long-term commitments and significant investments required to tackle the sustainable generation and use of energy. The partnership focuses on the acceleration of technology (especially low emissions technology), and collaboration between governments, business and research organisations to foster innovation and to implement practical, achievable, economically sustainable solutions to climate change. The partner countries believe these focus areas are essential to a sustainable solution to climate change.

The Asia-Pacific Partnership has established eight public-private task forces to examine cleaner fossil energy, renewable energy, power generation and transmission, aluminium, building and appliances, cement, coal mining and steel. Australia leads the task force on coal mining. Each task force has developed an action plan, describing the project activities that will be undertaken.

National policy response

Government has available a range of policy responses to address climate change and provide incentives for implementation of available mitigation measures. These include providing direct or indirect incentives or disincentives, such as subsidies, penalties, taxes, education programs, research funding and market-based mechanisms. All levels of government are examining available options.

The Australian Government has implemented a wide range of policies and programs aimed at reducing Australia’s greenhouse gas emissions. Measures including scientific research, industry development support, pilot scale demonstrations, abatement projects, education and strategic policy support have been implemented, at a cost of over $2 billion. Major initiatives of relevance to the primary industries sector include:

- establishment of the Australian Greenhouse Office (AGO)
- investment of $40 m to develop the National Carbon Accounting System, used to estimate emissions from agriculture and forestry
- $100 million Renewable Energy Development Initiative
- the Greenhouse Gas Abatement Program, to support activities that will give substantial abatement during the period 2008–2012

- $500 million for the Low Emissions Technology Demonstration Fund to support industry-led projects to demonstrate low emissions technologies with a high potential to lower Australia's future emissions
- Greenhouse Challenge Plus, which encourages emissions reduction by industry, and includes the 'Greenhouse Friendly' program of product certification
- the Mandatory Renewable Energy Target, to achieve a 95 000 GWh increase in electricity from renewable sources by 2010
- the Biofuels Initiative, which has set a target of 350 ML of biofuels to be marketed by 2010.

National actions by the Commonwealth, in conjunction with state governments, agencies and industry include:

- CRC for Greenhouse Accounting (finished 2006), CRC for Coal in Sustainable Development, CRC for Greenhouse Gas Technologies; CRC for Clean Power from Lignite (finished 2006)
- Council of Australian Governments (CoAG). The CoAG Climate Change Group (CCCG) was established following its 10 February 2006 meeting to implement the Plan of Collaborative Action on Climate Change. This group interacts with the work of the Natural Resource Management Ministerial Council, which has directed working groups to draft a set of national action pans for biodiversity, agriculture and marine ecosystems. See http://www.coag.gov.au for more details.

The policies and measures implemented by the Commonwealth, state, territory and local governments are impacting on emissions. It is estimated that these programs will reduce national emissions in 2010 by 87 Mt CO_2-e (AGO, 2006b), and that, in the absence of these programs, 'business as usual' emissions would be 125% of 1990 emissions by 2010.

NSW Policy response

The greenhouse policy measures implemented by the NSW Government are listed in Appendix 1.

Major initiatives are:

- carbon rights legislation – the NSW Government introduced the world's first carbon rights legislation in 1998, recognising carbon sequestration in forests, and allowing the separate ownership, sale, and management of these carbon rights
- the Greenhouse Gas Abatement Scheme (GGAS), which was the first mandatory emissions trading scheme in the world (see 'Emissions trading' below)
- the NSW Greenhouse Plan, with $24 m over 4 years for the Greenhouse Innovation Fund, which provides funding for initiatives under the Climate Change Awareness Program, Climate Action Grants Program, Climate Change Impacts and Adaptation Research Program, Climate Change Adaptation Capacity Building Program, and Greenhouse Gas Emission Reduction Projects Program.
- the NSW State Plan – Priority E3 in the 'Environment for Living' section of the State Plan – 'Cleaner air and progress on greenhouse gas reductions' – has a target to cut greenhouse gas emissions by 60% by 2050. Priority E2 – 'A reliable electricity supply with increased use of renewable energy' – includes a target of 15% renewable electrical energy by 2020.

9.10 EMISSIONS TRADING

Emissions trading creates a market mechanism to shift the price burden of emissions reduction to those activities that can achieve mitigation at the lowest cost; thus, emissions trading is a cost-effective mechanism for encouraging industry to reduce greenhouse gas emissions.

The success of emissions trading in reducing emissions depends on the establishment of a target for emissions at a level that achieves the mitigation required, while sharing liability amongst the emitters and enforcing compliance.

A greenhouse gas emissions trading scheme may include credits generated by mitigation activities in the forestry and agriculture sector, such as carbon sequestration in biomass and soil. Appendix 2 outlines emissions trading schemes operating internationally and in Australia.

The Kyoto Protocol created a market for greenhouse gas mitigation, by allowing parties to trade credits in order to meet their targets. Credits can be generated by abatement activities, or by sequestration activities that offset emissions. The Protocol recognises sequestration activities in the agricultural and forestry sector as legitimate offsets that can contribute to meeting the urgent need to reduce GHG emissions.

New South Wales Greenhouse Gas Abatement Scheme

The NSW Greenhouse Gas Abatement Scheme (GGAS), which commenced on 1 January 2003, aims to reduce greenhouse gas emissions from electricity generation. The GGAS imposes mandatory emission limits on all NSW electricity retailers and some large electricity users, known collectively as the ‘benchmark participants’. The scheme aims to reduce per capita emissions to 5% below 1990 levels by 2007. The scheme has recently been extended to 2020.

To meet targets, benchmark participants offset excess emissions through the surrender of NSW Greenhouse Abatement Certificates (NGACs), which may be created through low emissions intensity electricity generation, demand side abatement, and carbon sequestration in eligible forestry activities.

Eligible forestry activities are afforestation and reforestation of NSW land that was cleared before 1990. Forest owners must meet strict requirements for documentation of inventory methods and forest management, as well as record keeping. Regular monitoring is required, and projects are independently verified by registered auditors.

Five entities are currently accredited to generate certificates from forest projects: Forests NSW, CO_2 Australia, Australian Forest Corporation, Go-Gen Australia and Mallee Carbon. Forests NSW was the first entity to complete the audit process and commence trading; the first trade of forest NGACs took place between Forests NSW and Energy Australia in March 2005.

Proposed National Greenhouse Gas Emissions Trading Scheme

In January 2004, the first ministers of the state and territory governments established a working group of senior officials (subsequently named the National Emissions Trading Taskforce – NETT) to develop a model for a national emissions trading scheme (NETT 2006).

The task force released a discussion paper on 16 August 2006 outlining a proposal for a National Emissions Trading Scheme (NETS). The discussion paper argues that emissions trading is a practical, flexible and cost-effective means of achieving an emissions target, particularly for the energy sector. The comment period on the discussion paper closed in December 2006.

The essential elements of the proposed scheme are that:

- emissions are capped at a specified level in each period
- permits to emit greenhouse gases are issued for each period
- there is a penalty for noncompliance which underpins a value for emissions
- participants can trade these permits among themselves (NETT 2006).

The price of permits will not be set by governments; rather, it will emerge from the market, subject to any upper limit set by governments to constrain economic impacts. Firms are more likely to willingly pay for permits if their internal abatement costs are higher than the permit price, and they would be willing to sell permits if the revenue received from doing so exceeds the profits gained from using the permits.

The proposed scheme aims to deliver environmental integrity, investor certainty, minimal impact upon the economy, minimal increase in electricity charges to consumers, flexibility and equity.

Initially, the scheme will be limited to electricity generation, with other sectors to be considered in the first review period. Permits are to be made available to liable parties through a combination of direct allocation and auctioning. To reduce the financial burden on energy-intensive industries and minimise the pressure to relocate offshore, permits will also be allocated to trade-exposed energy-intensive industries. The proposed scheme will allow offset projects to generate credits. Offsets proposed for inclusion from the commencement of the scheme are reforestation, carbon capture and storage, management of emissions from industrial processes and management of methane from waste. Revegetation, forest management and management of cropping and grazing lands are proposed as areas for inclusion in future.

It is argued that an emissions trading scheme will make renewable and clean coal technologies economically viable and price competitive. Inclusion of forest and agricultural management as eligible offsets will provide an incentive for reforestation, and encourage agricultural practices that have mitigation benefits.

Prime Ministerial Task Group on Emissions Trading

In December 2006, the Prime Minister established a government-industry task group to ‘advise on the nature and design of a workable global emissions trading system in which Australia would be able to participate’. The report of the task group was delivered on 31 May 2007, recommending that Australia introduce a cap and trade system by 2012. It recommends broader sectoral coverage than the NETT proposal, including all energy, industrial and fugitive emissions. It proposes that the agriculture and land use sector emissions be excluded until practical issues associated with measurement and verification are resolved, but that offsets generated by this sector should be included, prior to full coverage of the sector. The report specifically recommends that carbon in wood products should be recognised by the scheme.

10 CURRENT NSW DPI INITIATIVES AND LINKS

NSW DPI is involved in a range of climate change initiatives. Previously, much of the research undertaken by the department focused on assisting industries in managing the impacts of climate variability. This research has provided a solid base from which to build research programs designed to assist industries in adapting to climate change.

The department has established a climate research unit, a climate risk management team and a range of internal and collaborative initiatives in all NSW DPI divisions, many of which are outlined below. Distributed across the divisions, NSW DPI has considerable research capacity to address many of the climate change issues. Expertise ranges from statistical and biophysical modelling, animal and plant physiology and breeding, to economics.

Mitigation

Through Forests NSW, NSW DPI has undertaken the world’s first carbon dioxide emissions trade for carbon sequestration by planted forests, under the NSW Greenhouse

Gas Abatement Scheme, and developed sophisticated carbon accounting procedures to support its emissions trading business.

NSW DPI is continuing research into carbon storage in wood products in landfill, and working on forest carbon accounting procedures that better reflect the fate of timber products after harvest (the current NSW GGAS excludes the mitigation contribution of carbon stored in wood products).

The department is undertaking a pilot project with catchment management authorities (CMAs), funded through the NSW Greenhouse Plan, to develop a system whereby CMAs can act as carbon pool managers on behalf of landholders, to facilitate participation in the GGAS carbon trading market, and thereby provide an incentive for revegetation.

As part of the WEST 2000 Plus-initiated Enterprise Based Conservation pilot program, NSW DPI is evaluating the practicality of an incentive system for Western Division graziers that provides financial incentives for maintenance or improvement of ground cover (mostly in the form of grass/shrub litter in summer rainfall areas, or cryptogamic crusts in winter rainfall areas). Such a scheme might be included in a national emissions trading scheme, along with other agricultural offsets.

NSW DPI is continuing research into the use of recycled organics in agriculture and forestry as a soil amendment to supply nutrients and sequester carbon, including application in mine site rehabilitation.

The department has commenced research into the use of char as a soil amendment to sequester carbon and improve water holding capacity and nutrient cycling.

NSW DPI is collaborating with Department of Environment and Climate Change in several projects, with funding from NSW Greenhouse Gas Emissions Reduction Projects Program and Climate Action Grant Program, to develop cost-effective methods of measuring soil carbon, and determine the impacts of alternative management practices on soil carbon stock.

The department is continuing research to:

1. quantify the mitigation resulting from selection of beef cattle for improved net feed efficiency in Australia, both at an individual animal and a national herd level
2. quantify the animal productivity and methane mitigation benefits of modifying gut ecology by eliminating ciliate protozoa from the rumen
3. develop new methodologies for measurement of methane production by ruminant livestock, to estimate energy expenditure and potentially estimate energetic efficiency of cattle.

NSW DPI is contributing to the Cooperative Research Centre for Greenhouse Gas Technologies (CO_2 CRC), which is focussing on geo-sequestration.

The department is exploring possible involvement in the Coal 21 initiative, a collaboration between the coal and power industries and state and national governments that aims to reduce or eliminate greenhouse gas emissions from coal-based electricity generation in Australia.

NSW DPI is actively involved in bioenergy activities through participation in Bioenergy Australia (peak government-industry forum) and by representing Australia at the International Energy Agency Bioenergy forums on ‘Short rotation crops for bioenergy systems’ and ‘Greenhouse gas balances of biomass and bioenergy systems’.

Through the Future Farm Industries CRC, NSW DPI is working with Victoria, Western Australia and South Australia to investigate the suitability and capacity for bioenergy production of native woody species that may be integrated into farming systems in the 300–700 mm rainfall zone.

The department has formed an alliance with the University of New England, to create the Primary Industries Innovation Centre. Biofuels and biomass energy have been identified as a key future program at the centre, and alliances with industry and researchers are being pursued.

NSW DPI worked with Department of State and Regional Development to produce a development strategy for biofuels in NSW.

Adaptation

The department has established the climate risk management team, to assist farmers in improving their short-term decision-making in response to seasonal climate variability. The team also undertakes a broader extension and education role for farmers, on climate change and climate variability.

Land & Water Australia’s Managing Climate Variability Program funds two NSW DPI projects aimed at improving seasonal risk management for rangeland graziers, western CMAs and subtropical dairies.

NSW DPI is working with the Bureau of Meteorology to undertake research to downscale global climate models, to get a better picture of the impact of climate change on specific NSW primary industries and regions.

The department is continuing to breed and evaluate new plant varieties for agriculture and forestry, to cope with changed climatic conditions (e.g. drier conditions, shorter seasons and increased rainfall intensity).

NSW DPI is developing a range of paper-based and computer packages to help primary producers make better decisions in the face of climate variability.

The department is collaborating with national and international experts to conduct research into the direct effects of increased atmospheric carbon dioxide (plants use water more efficiently, but will require different nutrient balances; plants will suffer frost damage at higher ambient temperatures). The Hawkesbury Forest Experiment – a series of 12 m high whole tree growth chambers – has been established to examine the interaction between elevated atmospheric carbon dioxide and water availability in plantation forests.

Development of a Geographical Information System (GIS) based framework for assessing the risk of climate change for agricultural production systems is being conducted by the climate research unit. This framework will provide a tool for assessing the impact, vulnerability and potential adaptation options of the range of agricultural systems in NSW.

NSW DPI has informal links with the South-East Australian Climate Initiative (SEACI), a joint project between CSIRO, BoM, Vic DSE and AGO, coordinated by the Murray-Darling Basin Commission (MDBC), which aims to produce better methods and projections to assist in planning water resource management into the future. The project will consider the impacts on rainfall, regarding amount (inter-year variability, decadal trends and climate change), reliability and environmental responses. Only a small part of NSW (south of the Lachlan) is included in the study area.

The department’s research and extension staff are involved in work carried out by the CRC for Irrigation Futures, ranging from development of on-farm toolkits and methods for evaporation mitigation, through to understanding irrigation in the catchment context (system harmonisation). Though this research is not directly focused on climate change, the outputs will be important in helping the irrigation industry adapt to the changing conditions (see section 8.3).

NSW DPI is collaborating with CSIRO to undertake research into sustainable development of marine and freshwater ecosystems, to ensure that they are ecologically healthy as well as economically productive under the predicted impacts of climate change.

Detailed descriptions of some of the more advanced of the abovementioned projects are given in Appendix 3.

11 RECOMMENDATIONS: KEY RESEARCH PRIORITIES FOR NSW DPI TO MAXIMISE MITIGATION AND ADAPT TO CLIMATE CHANGE

Key research priorities for NSW DPI have been identified in each of the primary industry sectors. These priorities have been determined through interaction between the department, industry and other agencies.

Broadly, the response to climate change can be separated into three key areas: climate change modelling, mitigation and adaptation. It is recommended that NSW DPI considers expanding research activity in these priority areas:

Climate change modelling

- Development of regional climate change models by downscaling global climate projections. This requires enhanced capacity to translate probability-based global climate projections at the regional level, to develop regional climate change models/projections. It also requires the development of input response curves for the current climate, and the projected climate change scenarios for a range of sectors. Regional- and industry-scale models will inform adaptation and mitigation responses.
- Development of a Geographical Information System (GIS) based framework for assessing the risk of climate change for primary production systems.
- Development of vulnerability-based models for key primary industry systems. This will facilitate vulnerability assessment of key systems to test the capacity for the coping range to be extended by proposed adaptation strategies.
- Research into socioeconomic impacts of climate change and proposed adaptation strategies, as decision support for landholders and to inform policies for structural adjustment.
- Development of decision support systems, to assist primary industries in coping with increased climate variability.

Climate change mitigation

- Research into clean coal technologies, through:
    - full life cycle analysis of current and alternative coal-fired power generation systems
    - identification of sites suitable for geosequestration and, subsequently, pilot injection projects
    - trials of CO_2 capture from power generation plants, gasification and chemical looping technologies
    - research into co-firing a range of biomass materials in coal-fired power plants
    - investigation of the potential of photobioreactor systems, growing algae to produce biodiesel and using CO_2 captured from power stations.
- Research into mitigation options in agriculture and forestry, through:
    - full life cycle assessment of current and alternative farming, livestock and forest systems (including direct and indirect emissions and removals), in conjunction with quantifying the environmental footprint of major NSW crop and livestock production systems on the soil, water and atmospheric environment
    - development of production systems with enhanced carbon sequestration in biomass and soil, as well as lower life cycle emissions, that are sustainable with regard to all environmental attributes, and have the capacity to adapt to climate change

  - investigation of the potential for low-rainfall tree species to be integrated into farming systems, to provide environmental benefits in addition to carbon sequestration (e.g. salinity mitigation, biodiversity enhancement)
  - investigation into the viability of products such as biomass for bioenergy production (for liquid fuels and stationary energy), as well as composite wood products
  - research into methods of reducing methane emissions from ruminant livestock
  - research into methods of reducing nitrous oxide emissions from applied fertiliser
  - research into methods of managing emissions from manure in intensive livestock industries
  - research into the use of char and other recycled organics as soil amendments to sequester carbon, and to improve soil organic matter, water holding capacity and nutrient cycling.
- Development of technologies for the production of bioenergy and other bio-products from agricultural and forest biomass, through:
  - examination of a range of feedstocks for suitability for bioenergy production, including novel sources such as mallee eucalypts, woody weeds and algae
  - breeding for bioenergy traits (e.g. high-starch wheats, high-biomass grasses)
  - socioeconomic assessment of the impacts of a bioenergy industry on other NSW primary industries, and the macro-economic implications for the national economy
  - assessment of biochemical options, including the concept of biorefinery, whereby high-value chemicals are produced from biomass in addition to energy products.
- Development of the underpinning science to facilitate mitigation through emissions trading, through:
  - quantification of the impacts of management practices on soil carbon, in the major cropping, grazing and forest systems of NSW
  - parameterisation of models of soil carbon dynamics for NSW agricultural and forest systems
  - examination of soil carbon dynamics in NSW radiata pine forests. This will have a major impact on DPI’s returns from carbon trading under the NSW Greenhouse Gas Abatement Scheme
  - development of improved models of sequestration for dryland forest species and mixed-species revegetation
  - research into the role of forest products in climate change mitigation, including the effect of landfill type, management and environment on the rate and extent of decomposition of wood and paper products
  - development of acceptable methods for inclusion of wood products in carbon trading schemes, acknowledging their important role in continuing carbon sequestered during forest growth. This could result in increased revenues from carbon trading for forest growers (including NSW DPI), and further incentives to establish forests in NSW.

Climate change adaptation

- Development of resilient farming systems through the enhancement of strategies developed to cope with climate variability, in order to increase farms’ capacity to cope with the greater variability, trends in climate variables, and indirect impacts (fire, pests) anticipated under climate change, through:
  - breeding and testing of new plant varieties (for agriculture and forestry) with wider tolerance of climate variability, including the ability to tolerate warmer and drier conditions, shorter seasons, increased rainfall intensity and reduced frosts.

  Objectives for different species include breeding for increased tolerance of water stress, tolerance of high temperatures during grain fill, quicker maturity, and the lack of requirement for winter chill for bud burst
  - research into the interactive effects of increased atmospheric carbon dioxide in a water- and nutrient-limited environment on the growth of major crop, pasture and forest species. Good understanding of the impacts of climate change will inform adaptation strategies
  - research into the impacts of climate change on product quality in all agricultural and forest systems, in order to inform breeding programs and development of adaptation strategies
  - research into the impacts of climate change on pest and disease organisms, and the resulting impacts on agricultural and forest production systems
  - development of strategies for minimising water losses, both on-farm and at regional level
  - research into improved water use efficiency for irrigated agriculture
  - development of systems to minimise heat stress in the intensive livestock industries
  - research into the interacting impacts of grazing pressure and climate change on the resilience of ecosystems
  - research into the impacts of climate change on weeds and weed management, particularly herbicide efficacy
  - landscape management – benefits of categorisation to the land’s capacity for productivity, more targeted fertiliser management and revegetation
  - research to determine the adaptation capacity of different plant species.
- Research into sustainable development of marine and freshwater ecosystems, to ensure that they are ecologically healthy, as well as economically productive, under the predicted impacts of climate change, through:
  - evaluation of the impacts of alternative management and harvest strategies using large-scale biogeochemical ecological models
  - development of robust monitoring systems to aid understanding of the impacts of climate change, especially on recreationally and commercially harvested fish and invertebrates
  - research into the impact of climate change on ecological health
  - evaluation of proposed adaptation strategies for marine and freshwater fisheries
  - research into the impacts of increasing acidity of the oceans
  - research into the impacts of sea level rise on estuarine salt marsh communities.