Pastures in the high rainfall zone – their anticipated responses to climate change and their role in minimising net farm greenhouse gas emissions

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Abstract. *The projected climate change to a significantly warmer and perhaps drier New South Wales by 2050, gives notice that grazing enterprises will need to adapt to this climate in order to remain productive. It is likely that most pasture systems in higher rainfall zones of New South Wales will respond to reduced rainfall and increased temperature with a shortened growing season and therefore a smaller proportion of the year in which highly digestible feeds are available. Higher atmospheric* CO_2 *concentration can serve to increase both plant growth and also to increase water use efficiency which may serve to offset some of the negative effects in environments where fertility and soil moisture are not over-riding factors. Wider use of drought adapted species, particularly C4 plants and invasion of C4 weed species into existing pastures can be expected. As plans for an emissions trading system in Australia become a reality, it is likely that the costs of emissions along with potential offsets from mitigation will lead to restructuring of grazing enterprises. Details of the response of pastures to climate change are evaluated and the likely impact on productivity in the high rainfall zone modelled. The role of pastures in reducing emissions and sequestering carbon is also considered as part of managing net emission from the farm.*

Introduction

Climate change is increasingly a topic of concern to livestock producers in Australia, because of the potential physical impact on the biology of the production system, and the inevitable economic impact of an Emissions Trading Scheme (ETS). 2007 was the warmest year on record for New South Wales (NSW) and the Murray-Darling Basin and was the seventh consecutive year of below average rain for the state (BoM 2008). While this is clearly a time of drought, climate change is likely to make such periods both longer and more severe than we have previously experienced. The median projected climate change for NSW by 2050 (using mid-range emissions estimates) indicates this trend will continue, with an increase in mean annual temperature and evapotranspiration, but reduced annual rainfall (CSIRO and BoM 2007).

The productivity and ecological changes within Australian pasture ecosystems arising from such climatic change are only just being explored (Hall *et al.* 1998; Pittock 2003; Harle *et al.* 2007; Hacker *et al.* 2007). Economic implications of changing productivity and land use, as well as of including agriculture in carbon markets are now being evaluated (Gunasekera *et al.* 2007). The determination that the national ETS should include agriculture (Garnaut 2008) is pivotal in placing the grazing industries in the context of Australia's other greenhouse gas (GHG) emitting industries. While points of obligation and allocation in a national ETS remain to be determined, there is much effort being expended to evaluate the implications of climate change and an ETS for farmers individually (Keogh 2007), the NSW extensive industries as a whole (Hacker *et al.* 2007); and to build a national (agricultural) carbon accounting system (NCAS) that can accommodate management and mitigation options (Brack *et al.* 2006).

In comparison to rapid policy change, biological change in the paddock appears slow, however, the projected climate change means that graziers must be prepared to adapt to changed climate. The major contribution of enteric methane to Australian agricultural GHG emissions is apparent (Gunaskera *et al.* 2007) but the scope for grazing lands to sequester atmospheric carbon in regrowth, in new forests and especially soil carbon is not well quantified. Scientists are striving to review the response of plants to elevated CO_2 (Morgan 2005) and changed climate (Campbell *et al.* 2000; Hughes 2003) but also anticipate how this will affect the wider grazing system (Harle *et al.* 2007). System models estimating impacts of management decisions on net greenhouse gas emissions from farms are evolving (McKeon *et al.* 1993; Howden *et al.* 2003b; Alcock and Hegarty 2006; Johnson *et al.* 2008), but are not fully developed for all gases. This paper seeks to look at the relationship between pasture production and a changing climate in two ways. Firstly, to report the likely impacts of climate change on pasture productivity and composition in NSW into the future, and secondly, to consider how pasture production in a grazing system can be managed to minimise the net GHG emission from the enterprise.

Pasture responses to climate change in NSW

Projections of climate in NSW to 2050 reveal changes in total rainfall, rainfall distribution, temperatures and potential evapotranspiration relative to present characteristics (Figure 1). These climatic changes and elevated CO_2 concentrations will mean that pastures will be in a new microclimate by 2050 relative to what they are today, so a change in the pasture ecosystem can be expected. Some of the changes expected are outlined below. Reviews assessing pasture and grazing responses to climate change are available (Campbell *et al.* 2000; Morgan 2005; Smith *et al.* 2008).

Growing season and pasture growth

Early models of the Queensland grazing system on native pastures indicated that increased CO_2, together with warmer conditions would increase pasture growth and live-weight gain of grazing animals, but when accompanied by reduced rainfall (as now projected for NSW), reduced annual pasture growth (Howden *et*

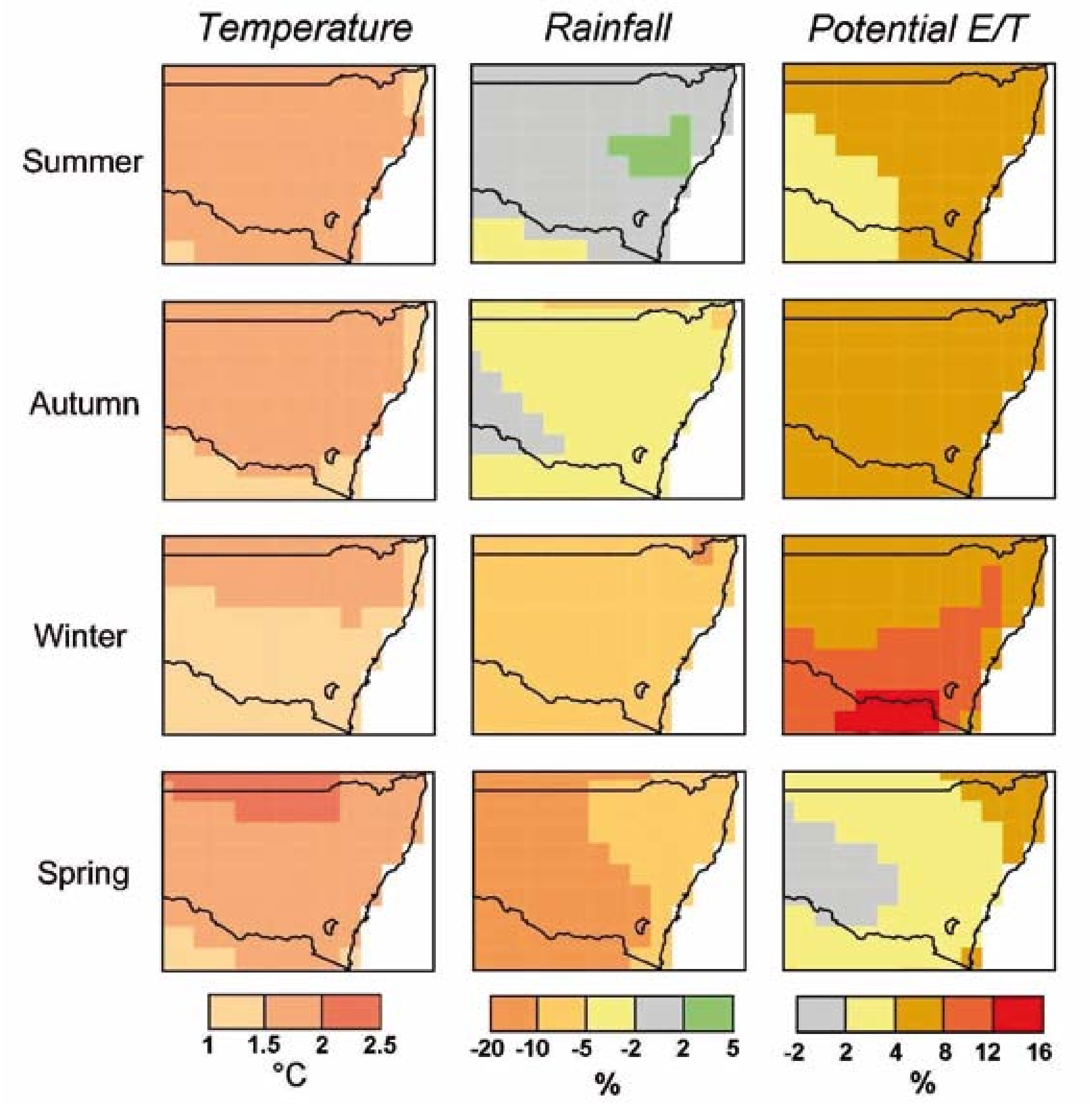

Figure 1. Best estimate of change in seasonal rainfall, temperature and potential evapotranspiration in NSW in 2050 assuming a medium emissions scenario. Change in projected parameters is given for 2050 relative to the period 1980–1999 (referred to as the 1990 baseline for convenience) and takes into account consistency among climate models. Individual years will show variation from this average. The 'best estimate' is taken as the mid point (50th percentile) of the spread of results from a range of global circulation models used to predict future climate. The medium emissions scenario refers to scenario A1B, from the IPCC Special Report on Emission Scenarios. Data are sourced from http://www.climatechangeinaustralia.gov.au/nswactevap17.php.

al. 1999a). We have used GrassGro (Freer *et al.* 1997, Moore *et al.* 1997) to simulate the productivity of a fine wool merino enterprise grazing an annual grass pasture at Cowra, NSW. GrassGro models the production of pasture and the performance of grazing livestock based on the impact of daily time-step weather data. Simulations were run using historical weather data from 1963–2002 and the same pasture system with synthesised weather data for mid-range projections for the climate in 2030–2069 (CSIRO 2001). The magnitude of the seasonal temperature and rainfall changes are shown in Table 1. This approach allows the impact of changed seasonal weather patterns and seasonal pasture growth to be accounted for.

Figure 2 shows the median pasture growth rates for the historical and future 40 year period and indicates that climate change may lead to a shortening of the growing season (the period where median growth rate exceeds 10 kg dry matter (DM)/ha/day) from 32 weeks to 26 weeks. The peak growth rates also appear reduced but in this case CO_2 fertilisation effects have not been accounted for and could potentially offset this effect. In a recent assessment of the likely impacts of climate change on the Australian wool industry to 2030, Harle *et al.* (2007) considered literature regarding the moderating effects of higher CO_2 levels on plant water-use efficiency. Overwhelmingly this literature points to enhanced plant growth under high CO_2, especially in water limited situations, presumably as a consequence of increased water use efficiency due to decreased stomatal conductance. Furthermore, modelling of C3 photosynthesis indicates that the thermal optimum for CO_2 assimilation may rise under elevated CO_2 (Sage and Kubien 2007) due to a shift in the relative photosynthetic limitations, assuming no other factors are limiting photosynthetic rate. However, while elevated CO_2 could offset the reduction in growth rate shown in Figure 2 it is unlikely to substantially ameliorate the impact of a shortened growing season.

Table 1. Average change to historical Cowra weather data projected for 2030–2069, expressed relative to 1963–2002 data

Season	Temp change (°C)^A	Rainfall change (%)^A	Evaporation (mm/day)^B
Summer	2.4	109	Estimated using corrected historical data for each season
Autumn	2.4	109	
Winter	2.0	92	
Spring	2.6	92	

^{A}Temperature and rainfall change after CSIRO 2001

^{B}Historical data was corrected using proportional increase in calculated EPan (FAO–56) for both historical and projected temps, solar radiation and constant wind; after Allen *et al.* (1998).

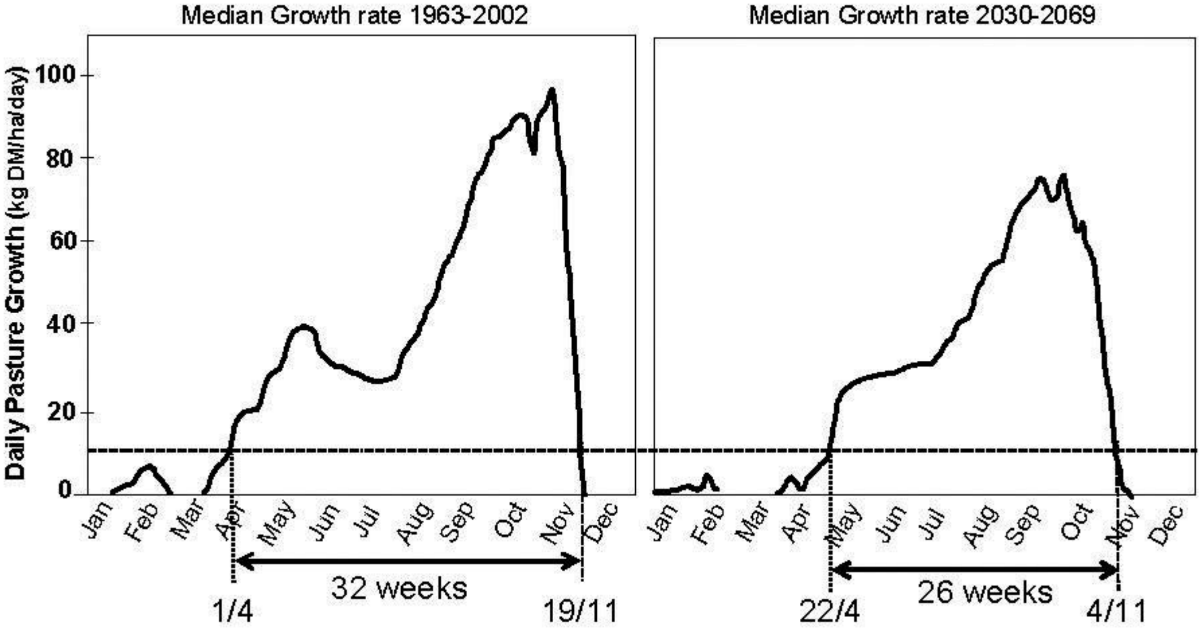

Figure 2. Effect of projected climate change on growing season length of annual grass based pasture at Cowra NSW as simulated using GrassGro 2.5.1.

Table 2. Effect of projected climate (2030–2069) on stocking rate and economic output of fine wool Merino enterprise relative to 1963–2002 climatic conditions

	1963–2002	2030–2069	Reduction (%)
Sustainable stocking rate	7 ewes/ha	5 ewes/ha	28
Average GM	$472/ha	$302/ha	36
Average Profit[A]	$382/ha	$212/ha	44

[A] Assumes overheads costs @ $90/ha

It is clear by comparing systems in a variety of climates that overall pasture utilisation rate is largely limited by length of growing season rather than by annual dry matter production, yet overall carrying capacity is affected by both season length and pasture productivity (Alcock 2006). In this simulation by relating herbage mass to ground cover and assuming a farm management objective to maintain summer/autumn ground cover above 70 per cent for at least 8 years in 10 (Warn *et al.* 2005), GrassGro indicates that Cowra will experience a reduction in sustainable carrying capacity from 7 ewes/ha to just 5 ewes/ha (Table 2).

These results assume the absence of adaptive management but this modelling approach may allow us to test the effectiveness of potential adaptation strategies in the future. Changing lambing times or the age at sale of young stock might help bring feed requirements back in line with the feed supply, especially if winter growth rates are increased due to CO_2 fertilisation.

Change in pasture species mix

In theory the impact of warming on a pasture ecosystem can be equated to moving the production further north to a drier, warmer climate. Howden *et al.* (2003b) indicated a 1°C change would be equivalent to relocating Melbourne to Wagga Wagga (NSW) under current conditions. In NSW there is also a shift in the seasonality of rainfall with latitude, in general moving from slightly winter dominant to a summer dominant pattern. In addition to rainfall, plant growth is photoperiod responsive (relative seasonal daylight hours) which will remain the same under a global warming scenario. For this reason it is not reasonable to expect that pasture ecosystems in a locality will automatically be suited to a locality further south as warming progresses. The most up to date climate change impacts are illustrated for Cowra in Figure 3. It can be seen that while the projected temperature data for Cowra overlays historical data for Coonabarabran quite well, Cowra's projected rainfall will remain non-seasonal compared with the summer-dominant pattern for Coonabarabran.

The most anticipated compositional change has been a shift in the C3:C4 species balance toward C4 species, due to changes in rainfall, temperature and extreme weather events (Howden *et al.* 1999b). While C4 are less responsive to elevated CO_2 (review: Sage and Kubien 2003), higher temperatures are considered likely to give C4 grasses a competitive edge as in previous world

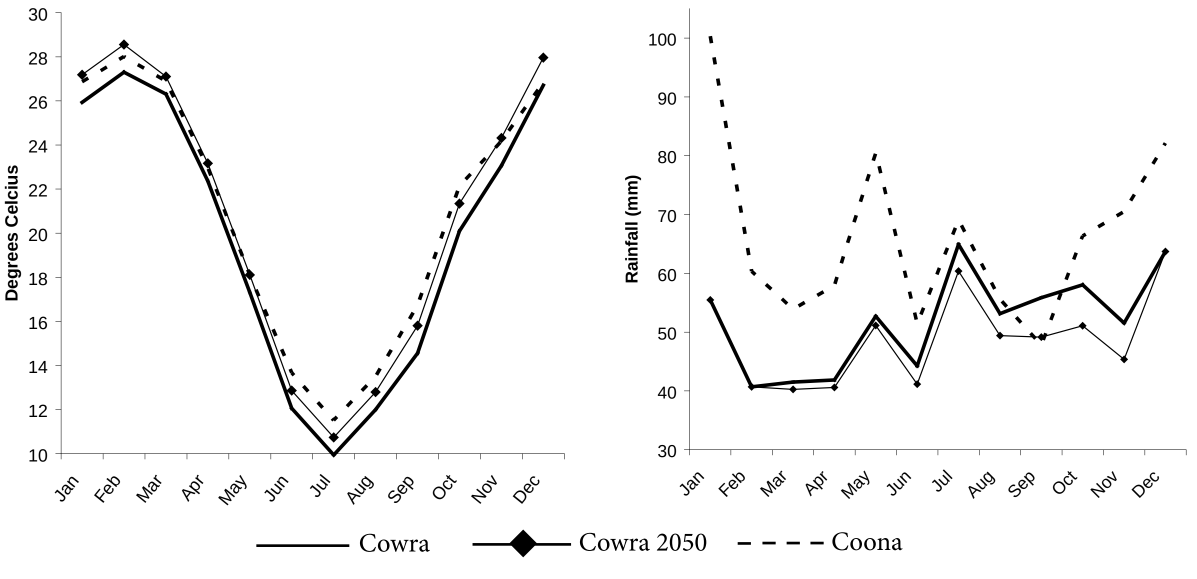

Figure 3. Historical lagged daily temperature and monthly rainfall (1980–1999) for Cowra and Coonabarabran compared to projected future climate parameters for Cowra (2050).

warming events ('t Mannetje 2007). Modelling by Howden *et al.* (1999b) for the C3:C4 balance in tropical Queensland suggests the isoline for where equal populations of C3 and C4 plants exist, will be moved south 100 km by a temperature rise of 3°C, and 250 km when combined with a doubling of atmospheric CO_2. While the warmer/seasonally drier scenario anticipated for NSW is consistent with inducing a shift to C4 species and C4 weed invasion as is being reported in Europe ('t Mannetje 2007), the non-seasonal to winter dominant pattern of rainfall in the southern half of the state may serve to limit this shift. Conversely, active management of pastures using such tools as grazing timing and intensity, pasture sowing and even fire, provide a rapid and powerful capacity to manage the C3:C4 balance in pasture, in ways that could readily reverse or accelerate climate-induced shift as desired.

It should also be remembered that C4 pasture plants are generally frost sensitive and the effect of climate change on frost risk is not as great as the effect on average temperature. In areas where frost is frequent (more than 40 frosts per year) the reduction in frost is only half the reduction that would be indicated by the average temperature increase (CSIRO and BoM 2007). This is the result of drier cool seasons and longer periods between rainfall events leading to more frequent 'clear sky' nights which offset the average temperature rise.

Pasture competitiveness and plant survival will also reflect differential species responses to elevated CO_2, microclimate changes and extreme weather events. In any one year, chamber studies of pastures under high CO_2 concentration revealed changes in the proportions of biomass contributed by component species (Morgan *et al.* 2004). Across years, CO_2 has been thought to change species balance by increasing flower number and seed number (review: Jablonski *et al.* 2002) but Australasian studies suggest this is a limited impact in native pastures. Free air CO_2 enrichment studies in open paddocks with elevated CO_2 in Australia's tropics, Tasmania and in New Zealand have been conducted (eg. Hovenden *et al.* 2007). These studies have found increased recruitment of some species due to increased seed production (Edwards *et al.* 2001) but germination does not appear to be affected. In Tasmania, where both CO_2 and temperature have been increased in small plots of natural temperate grassland (Hovenden *et al.* 2007), only five of the 23 species reported showed an effect of CO_2 or temperature on the percentage of plants flowering. In some years and some species, the number of inflorescences/plant produced was increased by CO_2 but most species showed no response.

Higher CO_2 alone may be expected to promote legume growth more than grasses (Picon-Cochard *et al.* 2004; Lilley *et al.* 2001), but given the drier winters and springs predicted for NSW in 2050, these effects may be negated by moisture stress. Importantly, higher evapo-transpiration and longer intervals between rainfall events (CSRIO and BOM 2007) in autumn may increase the risk of poor establishment of annual clovers.

Pasture quality

For a given species, dry matter digestibility may decrease with elevated CO_2 concentration (Morgan *et al.* 2004) or increase (Picon-Cochard *et al.* 2004), and results are likely to be confounded with time of cut relative to maturity and species, with little local research to report. Climate induced changes in digestibility are most likely to arise from accelerated maturation due to shorter growing season and a change in species balance due to CO_2 availability and microclimate. In general, a shift from C3 to C4 species would contribute to a decrease in both herbage digestibility and crude protein which would limit animal performance by comparison with current C3 dominant pasture systems. Importantly reductions in pasture quality will lead to higher methane output per unit of product from grazing animals, increasing the cost to grazing enterprises of any future ETS.

Pests

Just as changed climatic conditions will re-establish a new balance of C3 and C4 plants in each region, so local balances of plant, insect and microbial pests and diseases can be expected to change over time (Hughes 2003). Invasion with C4 weeds and pastures into C3 dominated pastures can be expected as outlined (Sage and Kubien 2003). CO_2 fertilisation studies have shown part of the species change with warming and CO_2 in Tasmania is greater presence of some weeds (Williams *et al.* 2007) in pastures.

Pasture management as a tool to reduce climate change

So far we have portrayed pastures only as structures responding to changes in CO_2 and to the temperature and rainfall of the environment in which they grow. It is equally true to assess pastures as agents influencing the net balance of greenhouse gas emissions leaving a farm. The example of Keogh (2007; p12) depicts that on a 'typical' southern NSW mixed farming enterprise (5,000 breeding ewes, 700 ha of cropping), 58 per cent of emissions are enteric methane and 31 per cent arise from nitrogen in soils and fertiliser.

Pasture management is a key tool in giving flexibility for the producer to move the balance between emissions and productivity. Alcock and Hegarty (2006), again using Grassgro to simulate a Cowra lamb producing property, were able to show that progressive pasture improvement (from annual pastures, low soil fertility) to fertilised perennial pasture (*Phalaris aquatica* plus 25 per cent legume), could give producers the option to:

- Maintain equal farm profit but graze a smaller area and reduce enteric methane emissions (from 5.3 to 3.0 t enteric methane/year)
- More than double farm profit but graze a smaller area and, maintain equal methane emissions
- Maximise gross margin (raised from $139 to $525/ha), improve all the grazing area and substantially increase enteric methane production.

These simulations did not include possible nitrous oxide loss from improved pastures, but as indicated by Keogh (2007), this is a minor source in extensive grazing systems. It should also be noted that current costs for pasture establishment exceed $300/ha (M. Keys, personal communication) and the cash-flow implications of development may mean that while cash-flow is enhanced the development as a whole may not break even for at least seven years.

Pasture management can also influence enteric methane, nitrous oxide and soil carbon losses by a range of other means as outlined below:

Pasture species

While the rumen digestibility of a plant affects the level of intake and methane loss/unit intake, (Hegarty 2001), specific non-fibre components of the plant can also affect methane production and potentially nitrogen excretion and volatilisation from paddocks. Examples of these are condensed tannins and organic acids.

Condensed tannins in species such as *Lotus* spp, have potential to reduce emissions by both reducing enteric methane and reducing loss of dietary nitrogen in urine. While it is recognised that condensed tannin activity varies among sources, tannins in pasture have typically reduced enteric methane emissions (Waghorn 2008). This is often achieved without compromising productivity and may be associated with other productivity benefits such as reductions in internal parasitism, susceptibility to bloat and urinary nitrogen, the latter possibly associated with lower N_2O emissions. (review: Mueller-Harvey 2006).

Many pasture species contain low levels of carboxylic acids such as the tricarboxylic aconitate and/or dicarboxylic malic and fumaric acids that can accumulate under some conditions (Stout *et al.* 1967). Some of these acids are known to be readily reduced to propionate upon entry to the rumen, thereby reducing hydrogen available for methane production (Lopez *et al.* 1999). Malate concentrations in lucerne may be up to 7.0 per cent of DM, so are at levels of organic acid believed sufficient to reduce methane production but these levels decline with maturity and vary with cultivar (Callaway *et al.* 1997). Recent studies of methane production by cattle consuming lucerne chaff showed daily emissions consistent with those predicted by published equations, indicating no evidence of lucerne chaff being a low methane-potential forage (R.S. Hegarty, unpublished data).

Grazing management for soil carbon sequestration

Soil carbon accumulation is one of the ways that graziers hope to be able to reduce net farm emissions or provide emission offsets for sale off-farm. Despite this, Australia has not agreed to Section 3.4 of the Kyoto protocol, thereby excluding Australia from including soil carbon in claimed sequestration (see Keogh 2007; p 11 for explanation). Nonetheless, there is enthusiasm for external schemes in their infancy which may enable landowners to be rewarded for increased soil carbon (eg. Jones 2007; Carbonlink 2008).

The principles of managing pasture to optimise residual sward state and grazing frequency are well established (Parsons and Chapman 2000) but their practical application in optimising animal management for productivity on-farm remains a topic for debate. The ramifications of pasture management on soil carbon accumulation have less data to support decision making, but the principles of plant growth used in optimising grazing frequency are instructive. Sources of soil organic matter include root dry matter, root exudates, leaf litter and the microbes associated with their decomposition. In pastures grazed to a low leaf area index (by intense grazing), there will be a low root mass and low litter loss into the soil. In pastures that are allowed to mature towards their ceiling yield, both root mass and litter mass will be maximised. Correspondingly, providing nutritional support to enable rapid pasture growth will be critical to active soil carbon (C) accumulation. Simply reverting cultivated land to unmanaged grassland led to only 30 kg C/ha/year (Burke *et al.* 1995), whereas converting crop-land to managed pasture typically accumulates at ten times this rate (~300 kg C/ha/year; Post and Kwon 2000). This should however be put into the context of grazing system emissions. For example, the GrassGro simulation of the Cowra based grazing system (descried previously in this text) indicates an average methane output of 64 kg/ha/yr (at a global warming potential of 21 times CO_2, this is equivalent to 1.34 tonnes of CO_2 emissions). Consequently, that land system would have to sequester an extra 365 kg of extra soil carbon per year to fully offset the methane emissions resulting from the introduction of livestock.

Species diversity also appears important to maximise soil carbon accretion, with accretion being greater for mixed swards than their component species grown in monocultures including C4 grasses and legumes (Fornara and Tilman 2008). In native species, differences in fine root (FR) production between Kangaroo grass (*Themeda triandra*; 17 g FR/pot/year) and Wallaby grass (*Austrodanthonia racemosa*; 4 g FR/pot/year) are apparent (Guo *et al.* 2005) and may also reflect their relative usefulness in building soil carbon.

While the scale and recognition of carbon sequestered under pastures remains to be defined in Australia, soil carbon sequestration must be seen in the context of concomitant farm GHG issues, some of which are listed below:

- Any continuously managed system will reach carbon equilibrium
- Rapid plant growth by which atmospheric CO_2 is sequestered will be dependent upon high nutrient and water availability. Forecast NSW climate change will periodically diminish pasture growth so even higher levels of inputs (with inherent potential nitrous oxide loss) may be required in periods when soil moisture and temperature are not limiting if overall pasture productivity is to be maintained or improved in the future
- Pastures are primarily grown for grazing, so pasture management (species, fertilising and grazing strategy) for minimising enteric methane production may not maximise soil carbon accretion or farm profit
- Benefits of adequate soil carbon include contributing to soil aeration, moisture holding capacity and exchangeable nutrient retention which may support enterprise profitability far more than the dollar value of the carbon itself.

As a land use change option, replacement of grazing systems (with their high enteric methane release) by alternative enterprises such as forestry has been considered, and large areas of grazing land have been converted to plantation forestry. Reversion of native pasture (*Themeda triandra*) to radiata pine plantation has led to substantially greater accrual of above-ground carbon (in trees relative to grass) but reduced the soil carbon pool (Guo *et al.* 2008). Other avenues of sequestration which do not exclude grazing should be considered. Pyrolysis of organic materials to produce biochar is one option that can be expected to provide sequestered carbon (in the char) and enhance the biological and biophysical properties of soils to promote pasture growth. In pot trials, biochar has been shown to increase cation exchange and field capacity while lowering tensile strength of the soil (Chan *et al.* 2007). While not yet commercially available, such results suggest biochar may have benefit as a soil ameliorant in both sandy as well as heavy clay soils.

Conclusions

By 2050, it is likely that NSW grazing enterprises in the high rainfall zone will encounter a shorter growing season in a warmer drier climate with a substantially reduced spring rainfall. Pollution of the atmosphere with GHGs will carry a direct or indirect cost to the enterprise and be part of the business calculation, as will potential returns from trading away the value of carbon sequestered on-farm. Pastures will provide a vital tool in optimising the financial viability of the farm. They will provide a food source for livestock, and their area, composition and management will be optimised to reduce GHG emissions from the stock grazing them; they will be a bank of carbon, either sequestered by plants into the soil or introduced as non-degradable carbon such as biochar. As such, the changing climate provides a bright future for the purposeful establishment and management of pastures as an underpinning component in the farming system.

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