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Systemic adaptations to climate change in southern Australian grasslands and livestock: Production, profitability, methane emission and ecosystem function

Afshin Ghahramani *, Andrew D. Moore

CSIRO Climate Adaptation National Research Flagship and Plant Industry, GPO Box 1600, Canberra, ACT 2601, Australia

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ABSTRACT

The annual net primary production (ANPP) of temperate grasslands and production of livestock industries is predicted to decrease in southern Australia with future climate change. By using biophysical modelling, we address productivity and profitability of grazing systems while considering systemic combination of grassland management and animal genetic improvement options. Single incremental adaptations will not completely avert declines in productivity and profitability; hence, combinations of adaptations are needed. The synergistic effects of these adaptations could potentially offset decreasing production and profit in 2030 over the majority of southern Australia, but not in some drier regions after 2030. These results demonstrate the need for changes in strategies over time with greater complexity of adaptations in drier regions. Upscaling over all southern Australia, financially optimal systemic combination (fully enhanced systems) could increase profit by 68.61%, 68.63% and 50.81% in 2030, 2050, and 2070, compared to the production of the historical period with current farm system management. Financially-motivated changes to grazing systems will result in improvement in grassland health, soil environment, and water use efficiency. However, full adaption of systemic adaptation will lead to greater ruminant CH_4 emission from 70 kg ha^{-1} yr^{-1} in baseline (1970–1999) to 84, 83, and 75 kg ha^{-1} yr^{-1} in 2030, 2050, and 2070. Higher rates of CH_4 emissions may affect profitability depending on future emissions pricing. In most of the drier regions, greater input intensity and management complexity may be required which requirement is likely to increase over time. However some of the drier regions would still require transformative adaptations.

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1. Introduction

A significant increase in temperatures and changes in annual and seasonal rainfall are predicted for southern Australia (CSIRO and BoM, 2012) owing to increasing anthropogenic green house gas (GHG) emissions (Houghton et al., 2001). Recently, more evidence has been presented for climate change, and little evidence has been presented regarding measures that prevent large climate changes (Stafford Smith et al., 2011). These changes are likely to affect agro-ecosystems worldwide (Schmidhuber and Tubiello, 2007).

Trends of changes in annual net primary productivity (ANPP) in response to elevated atmospheric CO_2, temperature, and rainfall have been reported at global (Melillo et al., 1993) and plot scales (Shaw et al., 2002). On a global scale, this increase is primarily related to the functions of tropical evergreen forests (Melillo et al., 1993). On a small scale (e.g., a plot), this increase is potentially related to increased rainfall and nitrogen and carbon fixation (Shaw et al., 2002).

In Australian temperate grasslands, however, the direction of projections differs from the global scale owing to likely decreasing rainfall during the growing season (Moore and Ghahramani, 2013). In southern Australia, average rainfall decreases of 4%, 6%, and 9% by 2030, 2050, and 2070, are predicted for the A2 scenario across 4 global climate models (GCMs), with corresponding projected temperature increases of 1.1 °C, 1.6 °C, and 2.5 °C in 2030, 2050 and 2070 (Moore and Ghahramani, 2013). These climate changes have been predicted to result in significant reductions in the productivity of grassland and livestock systems (Cullen et al., 2009; Moore and Ghahramani, 2013). In the first paper of this series (Moore and Ghahramani, 2013), we estimated that the ANPP (kg ha^{-1} yr^{-1}) of the grasslands would decrease on average by 9% in 2030, 7% in 2050, and 14% in 2070 relative to a reference period between 1970 and 1999, but with significant increases in the proportional contribution of legumes to ANPP. In the absence of adaptation, meat production at 25 locations across southern Australia was predicted to change between −92% and +10% at 2050 and wool production by between −95% and +2% (Ghahramani and Moore, 2013); the reductions in livestock production were driven by reductions in the stocking rate that could be sustained. Operating profit

* Corresponding author. Tel.: +61 2 624 648 92; fax: +61 2 6246 5166.
E-mail address: af.ghahramani@csiro.au (A. Ghahramani).

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(at constant prices) were estimated to fall by an average of 27% in 2030, 32% in 2050 and 48% in 2070 (Ghahramani and Moore, 2013). These reductions in productivity will profoundly affect an industry that provides some 20% of the value of Australian agricultural production. It is therefore important to know the potential for changes to the management of livestock systems to counteract this declining productivity and profitability. Evaluating adaptation options in an economic and environmental framework is likely to provide producers and policy makers with effective decision-making tools (Howden et al., 2007).

Despite the uncertainties that are associated with GCMs, biophysical models can help develop insights into the vulnerabilities of agro-ecosystems and the effectiveness of different adaptation options. In the second and third papers of this series (Ghahramani and Moore, 2013; Moore and Ghahramani, 2014) we have evaluated a number of potential grassland management and animal genetic improvement adaptations individually. Generally speaking, these adaptations could only recover part of the losses in profitability due to climate change impacts at 2050 and 2070. These two types of adaptations affect the water-use efficiency of livestock systems at different points, which indicated that they might be effective in tandem.

In this paper, therefore, we move beyond the evaluation of individual adaptation options and hypothesized that combination of feasible options would increase adaptation effectiveness and will offset likely negative impact by climate change on grassland and livestock industry. Our evaluation spans the dimensions of space and time and addresses different livestock enterprises in a combined economic and environmental risk framework. We assess the effect of adaptations on ecosystem function and tradeoffs with ruminant methane emission (cows and ewes) at a continental scale. The 33 M ha of grasslands in our study area encompass a diversity of climates and pasture species that have analogues in many temperate regions of the world (e.g., New Zealand, South America, South Africa and southern Europe).

2. Materials and methods

The methods used were consistent with those employed in earlier papers in this series (Ghahramani and Moore, 2013; Moore and Ghahramani, 2013, 2014). The GRAZPLAN biophysical models (Freer et al., 1997; Moore et al., 1997) were used to simulate the dynamics of coupled climate–soil–grassland–livestock systems at a daily time step. These models are widely employed in Australia for research purposes (e.g. Alcock and Hegarty, 2011) and for supporting producer decisions (e.g. Donnelly et al., 2002).

Grassland–livestock interactions were simulated for biophysical systems that included climate inputs, soil moisture dynamics, plant growth and pasture management (Moore et al., 1997) together with feed intake, nutrition, and reproduction of sheep and cattle (Freer et al., 1997). The effects of increasing temperature on grazing systems were described through model equations for plant phenology, assimilation rates, respiration, changes in herbage digestibility, seed dormancy release, germination, reduced intake due to heat stress, and perinatal lamb mortality. Effects of increased atmospheric CO_2 concentration on pasture growth were modelled on the basis of its impact on transpiration efficiency, radiation use efficiency, specific leaf area and herbage nitrogen content (Moore and Ghahramani, 2013). Livestock ruminant methane (CH_4) emissions were predicted using an equation derived from that of Blaxter and Clappert (1965). The soil moisture budget and infiltration were simulated with a model that was based on SWRRB (Moore et al., 1997).

Twenty-five locations (Appendix: Supplementary material 1) were identified to be representative of regions with approximately equal gross value of agricultural production across the agricultural lands of southern Australia. A representative set of land resources (weather, soils and pastures) was then described for each location. Soil and pasture information was collected from landholder workshops conducted by State agency officers where possible (Pattinson, 2011). Otherwise, published survey results (Dalgliesh et al., 2006; Forrest et al., 1985; Pearson et al., 1997) were used. Management systems representative of good practice at each location were specified for each of 5 livestock enterprises: Merino ewes producing fine wool and lambs for meat, Merino × Border Leicester crossbreed ewes with an emphasis on lamb production, Angus cows producing yearling or weaner steers and heifers, Merino wethers for fine wool production, and Angus steers (Appendix: Supplementary material 1). Common livestock genotypes were used for each enterprise across locations, but management practices for livestock replacement, the timing of the reproductive cycle, sale of young stock and supplementary feeding were described separately for each enterprise and location combination.

Climate projections from the Coupled Model Intercomparison Project (CMIP3) were used. The SRES A2 scenario (one of the higher emissions scenarios of the SRES) was selected because it represents a high-emissions future that is consistent with recent emission trajectories (Peters et al., 2012). To account for uncertainty in climate projections, projections from 4 GCMs with high relative skill over Australia were considered: CCSM3 (Collins et al., 2006), ECHAM5/MPI-OM (Roeckner et al., 2003), GFDL-CM2.1 (Delworth et al., 2006) and UKMO-HadGEM1 (Johns et al., 2006). Daily weather data were constructed for each projected climate with a downscaling technique that was adapted from Zhang (2007); see Moore and Ghahramani (2013) for further detail. A reference period of historical weather data (1970–1999) was simulated (with an atmospheric CO_2 concentration of 350 ppm). Future climates were projected for 2030, 2050 and 2070, with CO_2 concentrations of 451, 532 and 635 ppm, respectively (Houghton et al., 2001).

A further set of simulations of present-day grazing systems (systems being held constant with management and technology used in the baseline period), driven by historical weather and CO_2 concentrations from 1891 to 2010, was run to provide a longer-term context for the modelling results.

Candidate adaptation options for analysis were identified from literature reviews (Adger et al., 2003; Harle et al., 2007) and suggested by livestock producers in the workshops that were held during the project (our research was conducted within a larger program of research, development and extension (Pattinson, 2011). Eight potential climate change adaptations analysed individually in earlier papers in this series were further analysed in all possible combinations. Four of these were adaptations to grassland management (Ghahramani and Moore, 2013): (i) higher soil fertility through increased applications of phosphorus, (ii) confinement feeding, i.e. tactically placing animals in a feedlot during summer and autumn in years when pasture mass is low, (iii) sowing lucerne (Medicago sativa) on a proportion of land originally under grass-based pastures, and (iv) removing annual legumes from pastures in order to slow the rate of loss of ground cover over dry summers. The grassland adaptations (Ghahramani and Moore, 2013) were designed to increase ANPP and/or minimize periods of low ground cover to reduce the corresponding risk of soil erosion. The remaining four adaptations were cumulative improvements in livestock genetics: (v) increasing animal body size, (vi) achieving a greater conception rate, (vii) increasing potential fleece weight and (viii) increasing ram size. Further details of these adaptation options and the rationale for selecting them can be found in Ghahramani and Moore (2013), Moore & Ghahramani (2014).

Animal genetic improvement adaptations (Moore and Ghahramani, 2014) were designed based on historical genetic improvements (Gregory et al., 1997; Jeyaruban et al., 2009; Moore and Ghahramani, 2014; Safari et al., 2007) to increase their forage conversion efficiencies.

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