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Increasing ewe genetic fecundity improves whole-farm production and reduces greenhouse gas emissions intensities
1. Sheep production and emissions intensities

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ABSTRACT

Greenhouse gas (GHG) emissions from livestock constitute the largest proportion of Australian agricultural GHG emissions, necessitating development of strategies for mitigating GHG emissions from the livestock sector. Here we simulate a self-replacing prime lamb enterprise to examine the effect of increasing ewe genetic fecundity on whole farm GHG emissions, animal production and emissions per animal product (emissions intensity; EI).

Breeding ewes were a cross-bred genotype containing the Booroola (*FecB*) gene with average lambing rates of 1.5–2.0 lambs per ewe. Lambs were born in winter on pastures of phalaris, cocksfoot and subterranean clover, and were sold at the beginning of summer. Flock dynamics were simulated using the model GrassGro and whole-farm GHG emissions were computed using equations from the Australian National Greenhouse Gas Inventory.

Increasing ewe fecundity from a baseline of 0.96–1.54 lambs per ewe reduced EI from 9.3 to 7.3 t CO_2-e/t clean fleece weight plus liveweight (CFW + LWT) and GHG emissions per animal sold by 32%. Increasing fecundity reduced lamb sale liveweights and increased lamb mortality rates at birth, but this was offset by an increase in total liveweight turnoff. Greater ewe fecundity increased whole-farm productivity without increasing GHG emissions. For the same stocking rate as an enterprise running genotypes with lower fecundity, high fecundity genotypes either increased annual production from 449 to 571 kg CFW + LWT/ha with little change in net emissions, or reduced emissions from 4.2 to 3.2 t CO_2-e/ha for similar average productivity. In both cases, EI decreased by ca. 2.1 t CO_2-e/t CFW + LWT.

A foremost advantage of using high fecundity breeds is greater intra-annual variation in flock number, because such genotypes give birth to more lambs. This necessitates a reduction in the number of adult breeding ewes to maintain average annual stocking rate and benefits whole farm emissions, because breeding ewes contribute the largest proportion of farm emissions (77–80%), particularly enteric methane. We conclude that increasing ewe fecundity offers a win–win opportunity for the sheep industry by allowing sustainable intensification through greater production and lower emissions intensity, without adversely affecting net farm emissions or increasing stocking rate. High fecundity genotypes also present an opportunity for sheep producers to reduce stocking rates while maintaining current levels of farm production, thereby reducing labour and flock nutritional requirements.

1. Introduction

Emissions of greenhouse gases (GHG) from Australian agriculture in 2011–12 constituted some 15% of the nation's total annual GHG emissions (DCCEE, 2013). There is an increasing imperative to reduce emissions from the Australian agricultural sector, with the Federal Government introducing GHG offset schemes such as the Carbon Farming Initiative (CFI) to create opportunities for land managers to enhance productivity, obtain economic benefits and help the environment by reducing emissions (DCCEE, 2013).

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Greenhouse gas emissions from livestock currently form the majority of Australian agricultural emissions, and emissions from the livestock sector are projected to account for 72% of total agricultural emissions by 2020 (DCCEE, 2013). Past research examining strategies for GHG mitigation from the Australian livestock industry has primarily concentrated on emissions from Rangelands or tropical Savannahs in Australia's centre and north (e.g., Cook et al., 2010). There has been relatively little research of GHG mitigation strategies or technologies at the whole of farm level for enterprises in Australia's temperate south regions, either through manipulation of enterprise management or animal genotypic traits. Further, most research of GHG emission mitigation from livestock systems tends to be reductionist, focussing on either a single intervention strategy (e.g., rumen microbial manipulation), a single GHG (typically CH_4), or on measurements of GHG fluxes at the individual animal level (SF_6 tracer techniques). More whole-farm analyses of different intervention strategies to livestock enterprise management and animal genotype are required to generate a holistic view of biophysical feedbacks occurring within these systems, since such analyses can reveal important interactions between key variables. For instance, improving animal diet quality can improve liveweight gain with little change in production of enteric CH_4, leading to lower GHG emissions per unit animal product (hereafter, emissions intensity or EI). However, improved diet quality may also result in greater dry matter intake per animal, such that no net change or even a net increase in GHG emissions can be observed at the whole-farm level (Eckard et al., 2010).

A promising avenue for reducing net farm emissions and EI is the use of genotypes with higher fecundity (Cummins, 2011; Hristov et al., 2013). Garnsworthy (2004) found that increasing the reproductive rates of dairy cows reduced the number of heifer replacements required to maintain herd size for a given milk quota, reducing herd CH_4 emissions by 11% and NH_3 emissions by 9%. Cummins et al. (2009) showed that to produce the same amount of lambs annually as a lower fecundity genotype, use of ewe genotypes with higher fecundity enabled reductions in flock size, greater flock energy-use efficiency and enabled a greater proportion of farm area to be put to other uses.

Increased fecundity may not come without limitations. A review of the effect of a gene named after its effect on ewe fecundity (*FecB*, after 'fecundity-Booroola') presented evidence of higher non-pregnancy rates of genotypes homozygous for the *FecB* gene, lower birth weights and reduced lamb growth rates (Fogarty, 2009). Single-born lambs tend to have higher liveweights than those of twin- or triplet-born lambs (Fogarty, 2009) and receive more milk from their mothers, so their growth rates are generally higher than those of multiple progeny (Bailey, 2013). Single-born lambs continue consuming ewe milk for longer than multiple-born lambs, which are forced to begin earlier feeding on pasture (Bailey, 2013), and ewe milk has greater nutritional quality than most pastures (milk contains ~13 MJ/kg DM, whereas high-quality pasture contains ~10 MJ/kg DM; Stevens, 1999). Clearly, the effect of increased fecundity on sheep production and GHG emissions at the whole farm level depends on multiple factors and interactions. The aim of this study was thus to conduct a whole farm analysis to determine the effect of ewe fecundity on enterprise-level productivity, GHG emissions and emissions intensity (EI). The profitability and costs associated with introducing high fecundity sheep genotypes are examined in a companion paper (Ho et al., 2014).

2. Materials and methods

2.1. Biophysical simulations and weather data

Animal and pasture dynamics as affected by biotic (e.g., botanical composition, animal physiology) and abiotic (e.g., soil) conditions were simulated using the model GrassGro (Moore et al., 1997; Freer et al., 2012). GrassGro simulations have been extensively validated for pasture and animal data on sites throughout south-western Victoria in previous work (Browne et al., 2011; Cayley et al., 1998; Clark et al., 2003; Mokany et al., 2010; Moore and Harrison, 2011; Salmon et al., 2004; Warn et al., 2006a, 2006b). These validations have demonstrated credible model capacity in simulating biophysical data for sites in this region (Moore and Harrison, 2011). All simulations used daily weather data from 1970 to 2012 that was downloaded from the SILO repository (http://www.longpaddock.qld.gov.au/silo/) as a patched-point dataset (Jeffrey et al., 2001).

2.2. Site location, climate, soil characteristics and botanical composition

Data used in simulations were collected from a prime lamb enterprise near Cavendish in Victoria, Australia (37°S, 142°E) that had an arable farming area of 431 ha. Long-term minimum and maximum average daily temperatures at Cavendish are around 4 °C in July and 26 °C in early February. Long-term average annual rainfall at Cavendish is unimodal and normally distributed, with maximum and minimum monthly totals of 80 mm in August (winter), 25 mm in February (summer), and with a long-term cumulative total average of 672 mm/year. Following detailed soil surveys of the region (Perry, 1996), soil profiles in GrassGro were modelled as mottled yellow–brown chromosols overlying weathered granitic- or basaltic parent materials. Topsoils were modelled as hard-setting sandy-clay loams (300 mm deep) overlying mottled clay subsoil horizons (400 mm deep). Topsoil and subsoil bulk densities were also set in GrassGro in accord with observations by Perry (1996) at 1.4 and 1.7 mg/m^3, respectively. Plant available water capacity and saturated hydraulic conductivity were set at 42 mm and 30 mm/h in the topsoil and 40 mm and 3 mm/h in the subsoil, respectively. The GrassGro soil fertility scalar was set to 0.8, representing moderate fertility maintained through regular application of superphosphate (a GrassGro fertility scalar of 1.0 represents maximum fertility). Pastures consisted of phalaris (*Phalaris aquatica*), cocksfoot (*Dactylis glomerata*) and subterranean clover (*Trifolium subterraneum*), and were modelled as such in GrassGro.

2.3. Livestock genotype, traits and management

The case study property ran a self-replacing prime lamb enterprise with high fecundity ewe genotypes (Cummins et al., 2009). Past research has shown that genotypes containing the *FecB* gene (after 'fecundity Booroola') have higher reproductive capacity, larger litter size and higher meat production efficiency than genotypes without the *FecB* mutation (Cummins et al., 2009; Fogarty, 2009). The breed modelled here was developed over the last 30 years on the property and was originally based on Gromarks and East Friesian genotypes with other composite introductions. The current flock contained both homozygous and heterozygous carriers of the *FecB* mutation and was segregating with a *FecB* gene frequency of ~20%. Ewes aged between 20 months and 6 years were joined with rams on 28 February, with lambing occurring around 26 July each year. With exception of ewe lambs retained for the breeding flock, all lambs were weaned and sold at 18 weeks old on 1 December (long-term average liveweights at sale and carcass weights were 38–42 kg, and 16–20 kg, respectively). Mature ewes were shorn on 15 April and adults older than 6 years were cast for age on 31 January. Mature ewes and rams in condition score 3 weighed around 70 kg and 100 kg, respectively. Greasy fleece weight, fibre diameter and fleece yield of mature ewes were 3.9 kg, 32 μm and 72%, respectively. All animal data