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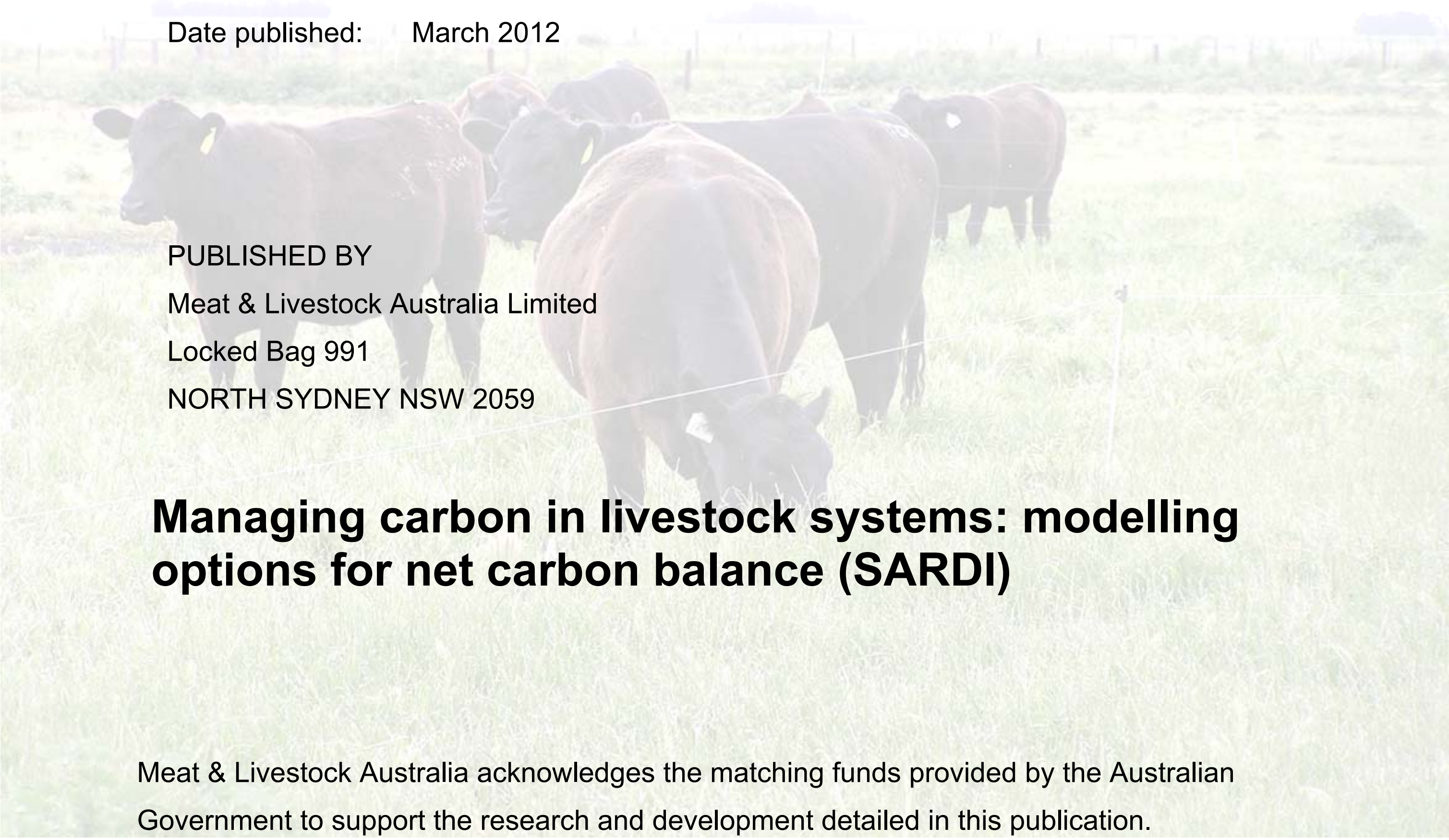

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Managing carbon in livestock systems: modelling options for net carbon balance (SARDI)

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Abstract

This study investigated greenhouse gas (GHG) emissions (tonnes of carbon dioxide equivalents; t CO_2e) and emissions intensity (t CO_2e/t carcase weight) of pasture-fed southern beef production systems by simulation modelling. Reasons for differences in yield and composition of GHG emissions and the effects of mitigation strategies were investigated.

Using the SGS Pasture Model the GHG emissions intensity of self-replacing beef cattle breeder operations were estimated at 16.33 to 18.61 t CO_2e/t calf carcase weight, mostly from methane. Trader/finisher cattle systems produced GHG emissions intensities of 10.83-12.79 t CO_2e/t steer carcase weight. Through manipulation of grazing management and making full use of the production potential of animals it was possible to reduce total GHG emissions from breeder operations by 12.2% while also increasing total calf carcase weight produced. Within trader/finisher operations, reductions in GHG emissions were found when either growth efficiency of animals was increased (up to 5% reduction) or maintenance efficiency was decreased (up to 4% reduction). When both effects were applied concurrently there was up to an 8.8% reduction in total GHG emissions intensity.

Thus it appears that grazing management and genetic selection are both viable means for livestock producers to reduce GHG emissions from their enterprises.

Executive Summary

As one of the major emitters of greenhouse gases it is incumbent on Agriculture, and ruminant livestock producers in particular, to investigate ways to control and reduce emissions from their livestock, even though agriculture is not currently (or forecast in the foreseeable future) to be taxed directly to encourage this effect. There is currently a dearth of information and data on greenhouse gas (GHG) emissions from livestock in southern beef production systems, and from South Australian livestock production in particular. In fact, it appears that this study is the first to investigate GHG emissions from livestock production systems in South Australia, even though this example is 'only' using modelling approaches. In an attempt to start addressing this situation this study aimed to identify the current net carbon balance and demonstrate a range of abatement options to reduce net carbon balance in southern beef production systems, with particular emphasis on cell grazing technologies.

The SGS Pasture Model was used to assess a range of production systems and scenarios for beef cattle in southern Australia (based on the South East of South Australia). The study examined self-replacing beef breeder and beef trader/finisher operations, focussing on production and management options that would be applicable to and achievable by beef cattle producers within the local region. Accordingly the self-replacing breeder operations simulated consisted of British-breed cows of 650kg mature weight, selling steer and excess/cull heifer progeny to grass or feedlot finishers at approximately 250kg. Trader/finisher simulations also focussed on British-breed cattle with steers being bought in to the enterprise at approximately 250kg and being grown at pasture to 550-600kg for slaughter at 2 years of age. As mentioned, these are 'typical' production systems for the region which has approximately 1.5 million beef cattle within 1.5hrs drive of Struan Research Centre where the study was based.

The GHG emissions intensity estimated in this study for self-replacing beef breeder operations ranged from 16.33 to 18.61 tonnes of carbon dioxide equivalents (t CO_2e) per tonne carcase weight, which compared favourably with results from the similar study by Browne *et al.* (2011). These emissions were predominantly made up of methane (CH_4) respired from cows and calves (14.19-15.28 t CO_2e/t calf carcase weight), with the minor component (17.9%) coming from nitrous oxide (N_2O) emitted from the pasture. In contrast, this study produced much higher GHG emissions for beef trader/finisher systems than those of Browne *et al.* (2011) – 6.3 to 7.7 t CO_2e/t steer carcase weight compared to 10.83-12.79 t CO_2e/t steer carcase weight in this study (although liveweights and production systems were also markedly different between the two studies). Nevertheless, the underlying message from these estimates is that the simulations reported for this project resulted in GHG emissions that were generally in line with other literature data.

This study also investigated a range of mitigation strategies that would be achievable by most beef cattle producers in the southern grass-fed production zone. For example, a change in grazing management from traditional (and still relatively common) continuous grazing to a rotational grazing system resulted in a very small reduction in total GHG emissions (1.8%). This appears to have been driven by an improvement in pasture utilisation and a reduction in pasture wastage, resulting in a significant effect on N_2O emissions from the pasture (27% reduction). When there was a planned attempt to capture many of the likely pasture effects of rotational grazing (i.e. more pasture grown, more pasture utilised, increased pasture quality and therefore increased overall diet quality) by increasing both animal growth rate and stocking rate, total GHG emissions were reduced by 12.2% while the total amount of product produced (calf carcase weight) also increased. Again this effect was driven by a large decrease in N_2O emissions (36%), presumably due to less pasture wastage. However a 7% reduction in CH_4respiration by the cows and calves in the simulations was also a significant contributor, due (presumably) to the improved nutritional quality of the pasture and the overall diet quality.

In the trader/finisher operations simulated in this study the effects of introducing less efficient or more efficient animals into the production system resulted in increasing (lower growth efficiency) or decreasing (higher growth efficiency) total GHG emissions due to changes in dry matter intake by the animals. It is expected that these results are the same as those that would result if the genetic fatness of the animals was manipulated. Similarly, manipulation of maintenance efficiency resulted in the expected effects of increasing total GHG emissions when the maintenance efficiency of the animals was decreased and increasing total GHG emissions when it was increased. Moreover, when both growth and feed efficiency effects were applied at the same time there was a large reduction in total GHG emissions (up to 8.8%). Thus it appears that increasing growth and/or maintenance efficiency are viable ways for livestock producers to reduce GHG emissions from their livestock enterprises.

The SGS Pasture Model simulations undertaken in this study indicate that GHG emissions can be reduced in a range of beef production systems in pasture-fed situations in southern Australia by improved grazing management and by genetic selection of more efficient animals. Significantly, these manipulations are relatively easily achievable in most beef cattle production systems and generally are not expensive to adopt. The significant question that remains from this work however is whether these modelled results are mirrored in the field. It is therefore extremely important to obtain actual field measurements of these GHG emissions under different grazing management systems and by using animals of different genetic merit and makeup (e.g. high vs low genetic fatness). If the measured effects in such studies were to mirror those reported here for modelled studies the uptake of the key findings is likely to be far greater and have a more rapid benefit to the livestock industry.

The project has also indicated a number of weaknesses with the main model used, the SGS Pasture Model, such as when trying to simulate a high intensity rotational grazing system such as the TechnoGrazing system used at Struan Research Centre and when trying to adequately simulate trader/finisher systems. These and some other minor weaknesses could be relatively easily addressed with continued support of the model developers.

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Background

South Australia makes a relatively small contribution to Australia's greenhouse gas (GHG) emissions – only a 5.6% share of national emissions in 2009 (30.8Mt CO_2e of 545.8Mt nationally; DCCEE, 2011a). A similar story holds for South Australia's contribution to the national agricultural GHG emissions, with the total amounting to 4.8Mt CO_2e in 2009 (coincidently this is also 5.6% of the national total of 84.7Mt for agriculture). This can be further split into 3.4Mt CO_2e from livestock and 1.3Mt from all other sources of agriculture (5.9 and 5.0% of national totals, respectively). Interestingly, South Australia has ~15% (10 million) of the national sheep flock (AWI, 2012) but only ~4% (1 million head) of the national cattle herd (MLA, 2011a), although it is also worthwhile noting that more than 10 million sheep and about ~1.5 million (6%) of the nation's cattle reside within approximately 1.5hrs of Struan Research Centre (i.e. South East of SA, lower SA Murray Darling Basin, western Victoria, lower Wimmera and Glenelg/Hopkins NRM regions – MLA, 2011a, b).

Despite the state's relatively low contribution to the nation's GHG emissions, the South Australian state government has stated leadership objectives of encouraging early action in reducing GHG emissions, demonstrating best practice in reducing GHG emissions and building capacity to tackle climate change (DPC, 2007). Furthermore, the state's 2007 greenhouse strategy (DPC, 2007) indicated an objective to reduce greenhouse gas emissions from the natural resources sector and increase carbon sinks – clearly an objective that will incorporate activities in and from agriculture. It appears, however that very little, if any, studies of GHG emissions from South Australian livestock production systems have been undertaken.

Browne *et al.* (2011) used GrassGro and DairyMod biophysical models to simulate a variety of livestock systems in south eastern Australia, however these were based on Victorian farm systems and data. In contrast, Peters *et al.* (2010) took a Life Cycle Assessment approach to analyses of red meat production in Victoria and New South Wales and Eady *et al.* (2011) also took a Life Cycle Assessment approach for two Queensland beef properties. None of these concentrated on the higher rainfall, Mediterranean environment of the south east of South Australia (and western Victoria) and the southern beef cattle production systems typical of these regions.

This study therefore appears to be the first to investigate livestock production systems 'typical' of South Eastern South Australia (and in this case also more generally southern Australia), estimating the level of emissions from southern beef cattle production systems. It is hopefully the first step in estimating and measuring emissions from southern production systems in the field. Potential abatement strategies, particularly those that can be taken up with minimal change to infrastructure and expense by cattle producers in the region – e.g. grazing management, utilisation of new or different genetics and changing management systems – are being examined in this study. While 'only' relying on modelling approaches, it appears to be one of the first examples of farm-level assessments of GHG emissions on a beef cattle property in South Australia and has the potential to assist in demonstration of these technologies to a significant producer audience.

Project objectives

The objectives of this project are the development of a range of option models to:

(a) Identify current net carbon balance, and

(b) Demonstrate a range of abatement options to reduce net carbon balance.

For the SARDI Struan Research Centre demonstration site this work focuses on southern beef production systems with special emphasis on cell grazing technologies.

The aim is to identify and discriminate the reasons for differences in yield and composition of carbon emissions and emissions intensities from (a range of) enterprises. Importantly, this work will demonstrate a number of mitigation or abatement options using modelling protocols that have taken their biophysical and economic inputs from actual farm sites.

In this case the data will come from commercial activities as well as research results from significant beef cattle operations at Struan Research Centre – including an existing Beef CRC Maternal Productivity research project.

Plate 1: Angus cows running on the Struan Research Centre TechnoGrazing system in late spring.

Methodology

1. The Struan Research Centre

The Struan Research Centre is located approximately 370km south east of Adelaide and 15km south of Naracoorte in the lower south east of South Australia (37^{o}10'S; 140^{o}48'E) and within 15km of the SA/Victorian border. The property lies on the edge of limestone ridges and comprises 250ha of sandy 'high' country and 832ha of floodplains (shallow dark clay loam (rendzina) overlying limestone - DWLBC, 2002). Good supplies of high quality underground water are available at shallow depth (3-4 metres) across the property and approximately 140ha are irrigated by flood and centre pivot systems. One hundred and ninety two hectares of the dryland area is dedicated to a high intensity rotational grazing system (TechnoGrazing™ - KiwiTech International Ltd: Bulls, New Zealand) that has been used as a research tool in grazing systems and as a commercial livestock growing and finishing system. This system has been used for intensive animal and pasture monitoring in a Beef CRC research project (Beef CRC, 2008) over the last 5 years, and will therefore provide most of the data to be used for this project.

The centre supports a largely phalaris-dominant pasture base, interspersed with annual ryegrass and strawberry clover. This pasture base (as well as 307 ha at Kybybolite 15km east of Naracoorte) in turn supports approximately 250 breeding cows (Angus dominant), 600 Friesian bulls and 5,000 breeding ewes. Struan Research Centre is reasonably typical of many properties in the region in terms of its soil and pasture types, livestock systems and grazing policies, but has the more innovative TechnoGrazing operation as a contrast to 'district average' grazing systems and as a demonstration of the potential of rotational grazing.

2. The region – south east South Australia

The central part of the South East of South Australia (i.e. around Naracoorte, near the Struan Research Centre) has a 'typical' winter dominant rainfall of ~550mm, with long term average rainfall for Struan/Naracoorte at 556mm, mostly occurring from April to October. Droughts are rare, however rainfall is significantly winter dominant and the climate generally one of hot, dry summers and cool, wet winters. Average maximum and minimum temperatures for Naracoorte also reflect the seasonal pattern for the region, peaking at a February average of 28.7^{o}C (minimum of 12.2^{o}C) and falling to an average maximum of 14.2^{o}C (min. 4.9^{o}C) in July. Pasture growth/accumulation for the last 8 years (based on Pastures from Space pasture growth rate data – www.pasturesfromspace.csiro.au) for the Naracoorte-Lucindale district council region indicates that the area typically grows about 6,000kg DM/ha/year (Figure 1 – range from 2,500 to 7,700kg DM). With its reliable rainfall, good supply and quality of underground water for stock and irrigation, fertile soils and improved pastures the region is a strong livestock producer as indicated by the significant livestock numbers for the region (2.79 million sheep and 598,000 cattle in the South East of South

Australia; approximately 10 million sheep and 1.5 million beef cattle within 1.5hr drive from the research centre; MLA, 2011a, b).

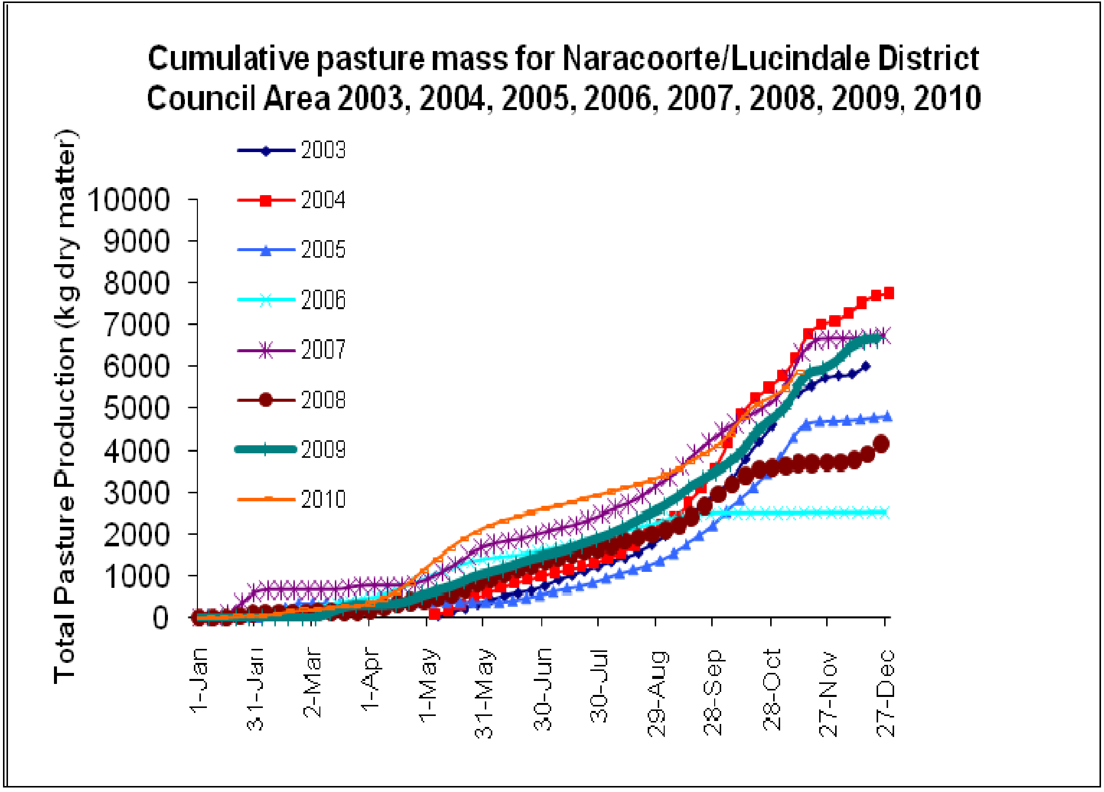

Figure 1: Cumulative pasture mass for the Naracoorte/Lucindale District Council region for 2003 to 2010 inclusive (collated from www.pasturesfromspace.csiro.au; Pastures from Space: CSIRO/DAFWA/Landgate, WA).

The region is well known for its grass-finishing of cattle and prime lambs, as well as for production of wool and first cross ewe lambs. Cattle enterprises are typically breeder and grass-fed cattle finisher systems, with some feedlotting. Supplementary feeding with a mix of silage, haylage, hay and grain over the hot, dry summer months is common practice, as is the use of hay in cattle rations for roughage during the lush winter/spring months. As is the case for the majority of southern Australia, Angus cattle dominate the local herd, with a range of other British breeds also common. Some cattle are also brought in to the region from northern Australia to finish on grass.

Despite its good production levels there is considerable potential to increase productivity in the region through better use of best practice pasture species, irrigation, soil nutrition management, increased intensification of grazing and modification of the grazing environment by addressing waterlogging, non-wetting soils and soil pH (McFarlane, 2002). Some of these options are investigated in this study.

3. Modelling GHG emissions

3.1 Models selected

The 2 models intended to be used in this project were:

1. The empirical model, FarmGAS Calculator (Australian Farm Institute Limited: Surry Hills, NSW) – this model enables property-level assessment of the greenhouse gas emissions implications of test scenarios. Assessments being undertaken using this model would only address the greenhouse gas emissions NOT the financial impact (Gross Margins) of these scenarios, which is also possible with this model. Furthermore, default values for emission factors would not be changed in the model (as is now possible with a new version of the model) so as to make the assessments comparable with other reported assessments (e.g. AFI, 2009; other RELRP modelling assessments such as Christie *et al.*, 2011). Training in the use of this model was delayed until late March, 2012. Analyses using this model have therefore not been completed in time for this report.

2. SGS Pasture Model (IMJ Consultants Pty Ltd: version 4.8.16; Johnson *et al.*, 2003) – this mechanistic biophysical simulation model of pasture systems includes modules for pasture growth and utilisation by grazing animals, animal intake and metabolism, water and nutrient dynamics, soil physical properties and a range of options for animal and pasture management, irrigation, and fertiliser application (farm management module). It is important to note that this model does not conform to Intergovernmental Panel on Climate Change methodology (IPCC, 1997) for estimating GHG emissions, as currently used in the Australian National Inventory (DCCEE, 2011b). This model estimates enteric methane emissions based on intake, with each kilogram dry matter (kg DM) of forage and concentrate equivalent to 19.89 and 13.26 g CH_4 emissions, respectively. It also estimates N_2O emissions from nitrogen fertiliser and animal dung and urine deposition, but again the methodology does not conform to the national inventory methodologies (DCCEE, 2011b).

   The strength of this model lies in its ability to simulate the impact of climatic and seasonal variability on pasture supply and how this influences farm management practices, such as stocking rate, grazing management practices or requirements for supplementary feeding. It is also possible to adjust many animal production parameters to simulate changes in genetic selection, animal growth, energy efficiency, etc. The model can also examine the dynamic nature of soil N_2O emissions based on varying soil parameters, climatic conditions and stock numbers.

3.2 Key model inputs

3.2.1 Climate Data in order to run the SGSL Pasture Model for Struan Research Centre (Latitude -37.0500; Longitude140.7500; Elevation 100m) was obtained through the Queensland Government's SILO Australian climate database (http://www.longpaddock.qld.gov.au/silo/) using the Data Drill function to access grids of data interpolated from point observations from the Bureau of Meteorology in the standard format, including FAO56 Reference Evapotranspiration (ETo). Data was obtained for the period 1/1/1889 to 19/12/2011, however only data from 1/1/1950 to 31/12/2010 (61 years) was used in the full model runs (cow/calf systems).

3.2.2 Soil Water Module parameters changed from the default settings in the model to better reflect the soil physical properties for the site (50cm of heavy clay soil overlying a layer of hard limestone (calcrete)) were as follows:

- Surface: 0-2cm; clay soil; Ksat = 3.6 cm/d; Bulk density 1.3 g/cm^3; saturated water content = 50% v; field capacity (-100cm) = 46%v; wilting point (-150m) = 28%v; air dry water content = 22%v
- 'A' horizon: to 10cm; clay soil; Ksat = 3.6 cm/d; Bulk density 1.3 g/cm^3; saturated water content = 50% v; field capacity (-100cm) = 46%v; wilting point (-150m) = 28%v; air dry water content = 22%v
- 'B1' horizon: to 30cm; clay soil; Ksat = 3.6 cm/d; Bulk density 1.3 g/cm^3; saturated water content = 50% v; field capacity (-100cm) = 46%v; wilting point (-150m) = 28%v; air dry water content = 22%v
- 'B2' horizon: to 50cm (maximum depth of soil at this site; next layer is calcrete); clay soil; Ksat = 3.6 cm/d; Bulk density 1.3 g/cm^3; saturated water content = 50% v; field capacity (-100cm) = 46%v; wilting point (-150m) = 28%v; air dry water content = 22%v
- Profile inclination = 0.1% (i.e. essentially flat and very little/slow runoff)

3.2.3 The Soil Nutrient Module "Initialisation option" was set to "*Use current system state*" and a simulation run from 1/1/1950 to 31/12/1999 (50 years) to set the initial soil conditions for all future runs. Subsequently this was reset to "*Use current initial conditions*" for all future runs so that they all started with the same initial soil nutrient conditions (9148.15 kg N/ha). In addition:

- Soil carbon was changed from default values to 5%; 4% labile and 1% inert to better reflect the local soil conditions

3.2.4 Pasture Growth Module parameters changed from default values were as follows:

- Phalaris selected as the dominant grass species; root depth was limited to 50cm due to the nature of the soil profile (see above); 20cm for 50% of root distribution
- Sub clover selected as the dominant annual legume; root depth was limited to 50cm due to the nature of the soil profile (see above); 15cm for 50% of root distribution; earliest date of emergence from 1 April annually; date of anthesis set at 1 November and 30 days from anthesis to maturity

3.2.5 Stock (beef cattle) Module parameters were set as follows for the base "Breeder" operation:

- 120 Beef cows; normal mature body weight = 650kg; minimum mature body weight = 400kg; initial body weight = 600kg
- Calving date = 1 April; 240 days from birth to removal of calf; average of 1 calf per cow
- Growth characteristics set at 'Sigmoidal growth curve'; Growth coefficient reduced from default of 2.0% to 1.3%/day (in order to achieve desired calf weight at weaning, which was based on current farm/project averages)
- Intake in relation to available pasture was modified such that unavailable dry weight was reduced from 0.5 down to 0.25t/ha to reduce the period of zero pasture intake that was occurring in initial simulations
- Supplementary feeding strategy was altered so that "*Implement critical % of ME requirement at which to feed dry cows*" was set at 90% AND "*Implement feeding in response to body weight*" was set to start at 550kg and stop at 600kg

3.2.6 Management Module parameters were set as follows:

- Single paddock; continuous grazing
- Farm with grazing area of 100ha

3.2.7 Model outputs were exported to Excel spreadsheets for analysis and collation of final results.

3.3 Key model outputs

Although the SGS Pasture Model produces a very extensive range of outputs, the relevant ones used as outputs of this project were:

- Pasture Intake (t/ha/year)
- % live (pasture) intake
- % dead (pasture) intake
- Total cut (pasture) yield (t/ha)
- Concentrate intake (t/ha)
- Forage intake (t/ha)
- Total rainfall (mm)
- N_2O emission (kg N/ha/year; t CO_2e/ha/year)
- Stock CH_4 respiration (t C/ha/year; t CO_2e/ha/year)
- Calf weaning weight (kg).

N_2O emissions and stock CH_4 respiration expressed by the model in t CO_2e/ha/year have been recalculated to various other formats for this report. They have also been summed to produce a "Total N_2O + CH_4" figure for each of these formats.

4. Cattle enterprises and abatement strategies modelled

The following scenarios were modelled for the project:

1. A 'typical' British-breed **self-replacing breeder operation** with low pasture utilisation (**continuous grazing**); selling steer and excess/cull heifer progeny to grass or feedlot finishers at ~250kg; mature cows 650kg.
2. A British-breed **self-replacing breeder operation**; moderate pasture utilisation (**<u>rotational grazing</u>**); selling steer and excess/cull heifer progeny to grass or feedlot finishers at ~250kg; mature cows 650kg. *To accommodate the change to rotational grazing the Grazing Strategy [Management Module] was set to 'Rotational' and:*

    1 April set to 60day rotation and minimum grazing residual reduced from 1.4t/ha to 0.5t/ha

    1 August set to a 28 day rotation and minimum grazing residual to 1.0t/ha

    1 November set to a 40 day rotation and minimum grazing residual to 1.0t/ha.
3. A British-breed **self-replacing breeder operation**; moderate pasture utilisation (**rotational grazing**) – as for (2) above - but with a number of other parameters then adjusted sequentially as follows:
    a. ***<u>Improved animal growth</u>*** *- Growth Coefficient [Stock Module] increased from 1.3 to 1.5 to simulate better calf growth due to improved pasture quantity and quality with rotational grazing*
    b. ***<u>Plus increased Stocking Rate</u>*** *- as for (a), but stock numbers also increased to 130 cows (and therefore 130 calves – Stock Module) to make better use of the increased pasture quantity and quality due to rotational grazing*
    c. ***<u>Plus reduced time to weaning</u>*** *- as for (b), but "Days from birth to removal" (of calves) reduced from 240 to 220 days (Stock Module) to simulate the effects of improved calf growth due to better pasture quantity and quality.*
    d. It was also intended to simulate further results from the current Beef CRC Maternal Productivity Project (Beef CRC, 2008) such as high rib fat EBV cows would be maintained in the herd for longer than low rib fat animals due to the effects of these parameters on cow longevity in the herd; unfortunately it was not possible to find a parameter in the model that could be changed to simulate this effect.
4. A British-breed grass-fed **<u>trader/'finisher' operation</u>**; moderate pasture utilisation (**<u>rotational grazing</u>**); buying steers at ~250kg and growing to 550-600kg for slaughter at ~2 years of age into MSA graded product. *N.B. this scenario required a different approach to the modelling when it was discovered that the Animal Management rules in the model are not well suited to simulate this kind of system. Instead of running the same 61 years of simulation automatically as for the breeder operation it was necessary to run a series of individual year simulations over the period 1/1/2000 to 31/12/2010, which was then collated into averages over that 10 year period. While this resulted in slightly different average climate data for the two contrasting scenarios (61 years of cow/calf @ 557.35mm vs 10 years of trader/finisher @ 513.64mm), this was a compromise to allow the trader/finisher operations to be modelled without taking an inordinate amount of time to manually collate the relevant data (i.e. 61 years of records!). Other parameters changed were:*

i. *Animal type [Stock: Beef Cattle Module] was changed to 'Steer'; starting body weight 250kg; intended maximum body weight 550kg*

ii. *Supplementary feeding strategy [Stock: Beef Cattle Module] changed to 'Implement critical % of ME requirement at which to feed steers' set at 60% AND 'Implement feeding in response to body weight' starting at 450kg and stopping at 500kg*

5. A British-breed grass-fed **trader/'finisher' operation**; moderate pasture utilisation (**rotational grazing**); buying steers at ~250kg and growing to 550-600kg for slaughter at ~2 years of age into MSA graded product, but utilising some of the outcomes and expected outcomes from the Beef CRC Maternal Productivity project (Beef CRC, 2008):

   a. *Using **22% lower Growth Efficiency animals** (based on the premise that low rib fat EBV animals are expected to finish more slowly than high rib fat animals) – simulated by changing the Growth Efficiency parameter [Stock Module – Energy tab] from 45% (default) to 35%*

   b. *using **11% lower Growth Efficiency animals** simulated by changing the Growth Efficiency parameter [Stock Module – Energy tab] from 45% to 40%*

   c. *using **11% higher Growth Efficiency animals** (based on the premise that high rib fat EBV animals are expected to finish more rapidly than low rib fat animals) – simulated by changing the Growth Efficiency parameter [Stock Module – Energy tab] from 45% to 50%*

   d. *using **22% higher Growth Efficiency animals** – simulated by changing the Growth Efficiency parameter [Stock Module – Energy tab] from 45% to 55%*

6. A British-breed grass-fed **trader/'finisher' operation**; moderate pasture utilisation (**rotational grazing**); buying steers at ~250kg and growing to 550-600kg for slaughter at ~2 years of age into MSA graded product, but:

   a. *using **lower efficiency (high Net Feed Intake (NFI)) animals** – simulated by increasing the Maintenance Coefficient [Stock Module – Energy tab] from the default of 0.48% to 0.51% (**6.3% increase**)*

   b. *using **higher efficiency (low Net Feed Intake (NFI)) animals** – simulated by decreasing the Maintenance Coefficient [Stock Module – Energy tab] from the default of 0.48% to 0.45% (**6.2% decrease**)*

7. A bull-beef 'finisher' operation run on a TechnoGrazing™ system (as per Struan Research Centre); grazing Friesian bulls on dryland pastures through spring and early summer; growing them from 250kg to 550-600kg for slaughter as low value grinding beef for domestic and export markets. This may include scenarios of nitrous oxide emissions due to high intensity of grazing/high fertiliser inputs - and possible mitigation strategies.

8. A bull-beef 'finisher' operation run on a TechnoGrazing™ system (as per Struan Research Centre); grazing Friesian bulls on dryland pastures through spring and early summer; growing them from 250kg to 550-600kg for slaughter as low value grinding beef for domestic and export markets, but using faster growing animals (e.g. low vs high rib fat or net feed efficiency).

Results

Initial simulation runs with the SGS Pasture Model indicated that the model did not include calf pasture intake in its methane calculations, resulting in under-estimation of enteric methane emissions for the cow-calf breeder systems being investigated in this study (B. Cullen, *pers. com.).* Estimated pasture intakes by the calves were subsequently used to calculate their methane respiration and these additional GHG emissions were added to those already predicted by the model; it is the sum of the model calculated emissions for the cow and the manually calculated emissions for the calf that are presented below.

1 GHG emissions from cows and calves (continuous grazing)

The base level GHG emissions from the modelled southern beef production systems (Scenario 1 - a 'typical' British-breed self-replacing breeder operation with low pasture utilisation (continuous grazing); selling steer and excess/cull heifer progeny to grass or feedlot finishers at ~250kg; mature cows 650kg) was **18.61 t CO_2e/t calf carcase weight/year** (or kg CO_2e/kg calf carcase weight/year), which is a combination of N_2O emissions and CH_4 respiration from both cows and calves (Table 1). The majority of the GHG emissions in this livestock enterprise are respired CH_4 from the cows and calves (**15.28 t CO_2e/t calf carcase weight/year**), with only 17.9% coming from soil N_2O emissions (**3.33 t CO_2e/t calf carcase weight/year**).

Other ways of presenting these values (e.g. per hectare, per cow or cow/calf unit or per kg calf liveweight) are also presented in Table 1.

Table 1: Greenhouse gas emissions (GHG) for continuously grazed cows and calves in a self replacing beef breeder operation (Scenario 1).

	N_2O emissions	**CH_4 respiration**	**Total N_2O + CH_4**
GHG emissions per hectare (t CO_2e/ha/year)	0.51	2.35	2.87
GHG emissions per cow & calf unit (t CO_2e/cow+calf/ year)	0.43	1.96	2.39
GHG emissions per tonne live product (t CO_2e/t calf liveweight/year	1.67	7.64	9.30
GHG emissions per tonne calf carcase weight (t CO_2e/t calf carcase weight/year)	3.33	15.28	18.61
Production data for the modelled 100ha 'farm'	Number of cows Number of calves	120 120	
	Average calf weaning weight	256.8kg	
	Total calf liveweight	30,811kg	
	Total calf dressed weight	15,405kg	(at 50% dressing)

2 GHG emissions from contrasting grazing systems (continuous vs rotational grazing)

Total GHG emissions from a modelled rotationally grazed southern beef self replacing cow/calf breeding production system (Scenario 2) that was otherwise identical to the continuously grazed system for Scenario 1 (above) was **18.28 t CO_2e/t calf carcase weight/year** (Table 2). Again the majority of the GHG emissions in this livestock enterprise were respired CH_4 from the cows and calves (**15.85** t CO_2e/t calf carcase weight/year from CH_4 respiration), with only 13.3% coming from soil N_2O emissions (**2.43** t CO_2e/t calf carcase weight/year from N_2O).

Comparisons between the continuously and rotationally grazed Scenarios (Table 2a) indicate that N_2O emissions are substantially reduced under a rotationally grazed system (28% on a per hectare or per cow/calf basis; 27% on a live or carcase weight basis). Methane emissions from livestock in the rotationally grazed scenario were elevated slightly over those under a continuously grazed scenario (2.3% on a per hectare and per cow/calf basis and 3.8% on a per tonne live or carcase weight basis). This resulted in a slight reduction in total emissions (i.e. N_2O + CH_4) – 3.1% decrease on a per hectare, per cow or cow+calf basis but only a 1.8% decrease on a live or carcase weight basis than the equivalent continuously grazed system (i.e. same number of animals; same growth parameters) (Table 2a).

Table 2a: GHG emissions and animal production for continuously vs rotationally grazed cows and calves in self replacing breeder operations (highlighted figures are lower than their respective contrasting grazing system).

	N_2O emissions		**CH_4 respiration**		**Total N_2O + CH_4**	
	Continuous grazing	Rotational grazing	Continuous grazing	Rotational grazing	Continuous grazing	Rotational grazing
GHG emission per hectare (t CO_2e/ha/year)	0.51	**0.37 (28% ↓)**	**2.35**	2.41 **(2.3% ↑)**	2.87	**2.78 (3.1% ↓)**
GHG emission per cow & calf unit (t CO_2e/cow+calf/year)	0.43	**0.31 (28% ↓)**	**1.96**	2.01 **(2.3% ↑)**	2.39	**2.31 (3.1% ↓)**
GHG emission per kg live product (t CO_2e/t calf liveweight/year	1.67	**1.21 (27% ↓)**	**7.64**	7.93 **(3.8% ↑)**	9.30	**9.14 (1.8% ↓)**
GHG emissions per kg calf carcase weight (t CO_2e/t calf carcase weight/year)	3.33	**2.43 (27% ↓)**	**15.28**	15.85 **(3.8% ↑)**	18.61	**18.28 (1.8% ↓)**
			Continuous grazing		**Rotational grazing**	
Production data for the modelled 100ha 'farms'	Number of cows Number of calves		120 120		120 120	
	Average calf weaning weight		256.8kg		253.2kg	
	Total calf liveweight		30,811kg		30,381kg	
	Total calf dressed weight		15,405kg		15,190kg	(at 50% dressing)

Table 2b shows that pasture intake was 13.2% lower for the rotationally grazed than the continuously grazed animals, however these animals consumed a greater proportion of live pasture(higher quality) than their continuously grazed counterparts (95% vs 89%). Furthermore, the intake of concentrates was 18% higher in the rotationally grazed animals and there was over a 100% increase in forage intake over the continuously grazed animals. There was also a significant quantity of excess pasture cut in the rotationally grazed system, indicating far greater pasture growth under this scenario (i.e. 3.81t consumed + 2.21t cut = 6.02t vs 4.39t consumed and none cut for continuous grazing = 37.1% increase). The total feed intakes were only 3.5% different between the two grazing strategies (6.21 vs 6.0 t/ha for the rotational vs continuously grazed scenarios).

Table 2b: Pasture, concentrate and forage intake for continuously vs rotationally grazed cows and calves in self replacing breeder operations.

	Continuous grazing	Rotational grazing	% change
Pasture intake (t/ha/year)	4.39	3.81	**13.2%↓**
% live intake	89.27	94.89	**6.3% ↑**
% dead intake	10.73	5.11	**52.4% ↓**
Total cut yield (= forage) (t/ha)	0	2.21	
Total pasture yield = consumed + cut (t/ha)	4.39	6.02	**37% ↑**
Concentrate intake (t/ha)	1.11	1.31	**18% ↑**
Forage intake (t/ha)	0.5	1.09	**118% ↑**
Total intake = pasture + concentrate + forage (t/ha)	6.0	6.21	**3.5% ↑**

3 GHG emissions when different growth parameters are included in an improved grazing management strategy

Only relatively minor changes in CH_4 (3.8%) and total (1.8%) GHG emissions were evident when the grazing strategy was changed from continuous to rotational grazing (see above – Scenario 2). One weakness of this comparison is that it does not take into account the potential increases in dry matter production, pasture quality and pasture utilisation that are likely to occur under rotational grazing nor these effects on potential stocking rate and animal growth. For this reason a number of additional scenarios were modelled to take these factors into account (Scenarios 3a-c; Table 3a).

In the first instance (Scenario 3a) the Growth Coefficient in the model was increased from 1.3 to 1.5 to take into account an assumed improvement in growth of calves as a consequence of improved grazing management, and its effects on improved pasture quality and quantity, plus the effects of more concentrate being used (i.e. overall increased nutritional quality of the feed consumed). This resulted in a 35.5% decrease in N_2O emissions per tonne calf carcase weight compared to the base continuously grazed scenario (Scenario 1 vs 3a - 2.15 vs 3.33 t CO_2e/t calf carcase weight/year). There was also a 6.4% decrease in CH_4 respiration, resulting in an 11.6% decrease in total N_2O + CH_4 emissions. At the same time there was a 13.2% increase in average calf weaning weight and a 13.3% increase in total calf carcase weight produced under this improved growth scenario.

It was also felt that it should be possible to run additional animals under the rotational grazing system, so stocking rate was increased (on top of the improved Growth Coefficient) from 120 to 130 cows and calves for Scenario 3b (8.3% increase in Stocking Rate). This resulted in a further reduction in N_2O, CH_4 and total N_2O + CH_4 emissions – 35.7% for N_2O compared to the continuously grazed system, 7.1% for CH_4 and 12.2% overall. As a consequence of the increased stocking rate there was also a 22.7% increase in total calf carcase weight produced compared to the continuously grazed scenario (but an almost identical weaning weight).

Table 3a: GHG emissions and animal production for continuously vs rotationally grazed cows and calves in a self replacing breeder operation with improved animal growth parameters to simulate better pasture utilisation and other effects of rotational grazing (figures in brackets indicate the % change in the parameter compared to the continuous grazing scenario). *Highlighted rows have already been presented in Table 2a.*

	N_2O emissions	**CH_4 respiration**	**Total N_2O + CH_4**	**Production Data for the modelled 'farms'**		
	t CO_2e/t calf carcase weight/year	t CO_2e/t calf carcase weight/year	t CO_2e/t calf carcase weight/year	Number of cows/calves	Average calf weaning weight (kg)	Total calf dressed weight (kg @ 50% dressing)
1. Continuous grazing (Table 2a)	3.33	15.28	18.61	120/120	256.8	15,405
2. Rotational grazing (Table 2a)	2.43 (**27.2%** ↓)	15.85 (**3.8%** ↑)	18.28 (**1.8%** ↓)	120/120	253.2	15,190 (**1.4%** ↓)
3a. Rotational + improved animal growth (improved pasture quality – increased Growth Coefficient in model)	2.15 (**35.5%** ↓)	14.29 (**6.4%** ↓)	16.44 (**11.6%** ↓)	120/120	290.8 (**13.2%** ↑)	17,450 (**13.3%** ↑)
3b. Rotational + improved growth & increased stocking rate (from 120 to 130 cows/calves)	2.14 (**35.7%** ↓)	14.19 (**7.1%** ↓)	16.33 (**12.2%** ↓)	130/130 (**8.3%** ↑)	290.9 (**13.3%** ↑)	18,908 (**22.7%** ↑)
3c. Rotational + improved growth + increased stocking rate + reduced time to weaning (reduced from 240 to 220 days)	2.33 (**30%** ↓; **8.8%↑ from 3b**)	14.95 (**2.2%** ↓; **5.3%↑ from 3b**)	17.28 (**7.1%** ↓; **5.8%↑ from 3b**)	130/130 (**8.3%** ↑; **no change from 3b**)	266.2 (**3.7%** ↑; **8.5%↓ from 3b**)	17,305 (**12.3%** ↑; **8.5%↓ from 3b**)

Finally it was felt that this improved animal growth should result in a reduced time for the calves to reach weaning weight, thus ‘days to weaning’ was reduced from 240 to 220 days (Scenario 3c - 8.4% decrease). Whilst this also resulted in a substantial increase in individual and total calf carcase weight produced compared to the base scenario (12.3% increase over continuously grazed) the increases were not as large as for either Scenario 3a or 3b (increased Growth Coefficient only and increased Growth Coefficient + Stocking Rate).

Table 3b shows that for the feed intake outputs from the model:

- Pasture intake increased as ‘enhancements’ were made to the animal system (i.e. 3.81 t/ha/year for the base level rotational grazing vs 3.94 for +improved growth vs 4.18 for +improved growth and increased stocking rate; dropped back to 4.00 with the shorter time to weaning)
- % live (pasture) intake remained similar at around 95% for all rotational grazing scenarios compared to 89% for continuous grazing
- Cut (pasture) yield decreased as the animal system was ‘enhanced’ to make better use of the feed (2.21 t/ha/year for the base level rotational grazing vs 2.12 for +improved growth vs 1.85 for +improved growth and increased stocking rate; the figure jumped back up to 1.92 when the shorter time to weaning scenario was introduced); cut yield was 0 under the continuous grazing scenario.
- Total pasture yield also increased, but only slightly over the base rotational grazing scenario (6.02 t/ha/year vs 6.06 vs 6.03 vs 5.92 respectively as above; 4.39 for continuous grazing)
- Concentrate intake increased as the animal system was ‘enhanced’(1.31 t/ha/year vs 1.34 vs 1.48 vs 1.45; 1.11 for continuous grazing)
- Forage intake also increased as the animal system was ‘enhanced’ (1.09 t/ha/year vs 1.14 vs 1.25 vs 1.23; 0.50 for continuous grazing)
- Total intake also increased slightly as the animal system was ‘enhanced’(6.21 t/ha/year vs 6.42 vs 6.91 vs 6.68 compared to 6.0 for continuous grazing)

Table 3b: Pasture, concentrate and forage intake for continuously vs rotationally grazed cows and calves in a self replacing breeder operation with improved animal growth parameters.

	Pasture intake	% live intake	% dead intake	Total cut yield	Total pasture yield	Concentrate intake	Forage intake	Total Intake
	t/ha/year			t/ha	t/ha	t/ha	t/ha	t/ha
1. Continuous grazing	4.39	89.27	10.73	0.00	4.39	1.11	0.50	6
2. Rotational grazing	3.81 (**13.2%↓**)	94.89	5.11	2.21	6.02 (**37.1%↑**)	1.31 (**18%↑**)	1.09	6.21 (**3.5%↑**)
3a. Rotational + improved animal growth	3.94 (**10.3%↓**)	95.06	4.94	2.12	6.06 (**38%↑**)	1.34 (**20.7%↑**)	1.14	6.42 (**7%↑**)
3b. Rotational + improved growth & increased stocking rate	4.18 (**4.8%↓**)	94.90	5.10	1.85	6.03 (**37.4%↑**)	1.48 (**33.3%↑**)	1.25	6.91 (**15.2%↑**)
3c. Rotational + improved growth + increased stocking rate + reduced time to weaning	4.00 (**8.9%↓**)	94.77	5.23	1.92	5.92 (**34.9%↑**)	1.45 (**30.6%↑**)	1.23	6.68 (**11.3%↑**)

4 GHG emissions from different cattle production systems (i.e. self replacing breeder vs steer trader/finisher operation)

Table 4a shows the GHG emissions from the highest production/lowest GHG emitting cow/calf breeder operation simulated (Scenario 3b - above) and a steer trader/finisher operation. This should not be taken as a direct comparison between the two systems, since the steer trader/finisher scenario does not include cow breeding emissions (i.e. maintenance costs and GHG emissions from the breeding side of the steer trader/finisher operation) that are included in the breeder scenario. The analyses do, however provide a point of reference for other scenarios that follow (Scenario 5 and 6 – below).

The key points to note from Table 4a are that the steer trader/finisher operation had higher N_2O emissions but lower CH_4 respiration than cow/calf breeder operation. Overall the trader/finisher system had 20% lower total GHG emissions. Table 4b also shows substantially lower levels of pasture, forage and total intake and a lower total amount of pasture grown.

Table 4a: GHG emissions and animal production for the optimum cow/calf breeder scenario (rotationally grazed/improved calf growth/higher stocking rate – Scenario 3b) and a steer trader/finisher simulation.

	N_2O emissions		**CH_4 respiration**		**Total N_2O + CH_4**	
	Cow/calf	Steer trading	Cow/calf	Steer trading	Cow/calf	Steer trading
GHG emission per hectare (t CO_2e/ha/ year)	0.41	0.63	2.68	1.62	3.09	2.25
GHG emission per cow & calf unit (t CO_2e/cow+calf or steer/year)	0.31	0.48	2.06	1.24	2.38	1.73
GHG emission per kg live product (t CO_2e/t calf or steer liveweight/year	1.07	1.83	7.09	4.70	8.17	6.53
GHG emissions per kg carcase weight (t CO_2e/t calf or steer carcase weight/year)	2.14	3.33	14.19	8.54	16.33	11.87

		Cow/calf	**Steer trading**	
Production data for the modelled 100ha 'farms'	Number of cows Number of calves/steers	130 130	0 130	*N.B. DSE rating of both cow/calf & steer was 10*
	Average calf weaning weight	290.9kg	-	
	Total calf or steer liveweight gain	37,816kg	34,407kg	
	Total calf dressed or steer carcase weight gain	18,908kg (at 50% dressing)	18,924kg (at 55% dressing)	

Table 4b: Pasture, concentrate and forage intakes for the optimum breeder scenario and a steer trading/finishing simulation.

	Cow/calf	Steers
Pasture intake (t/ha/year)	4.18	2.22
% live intake	94.90	93.90
% dead intake	5.10	6.10
Total cut yield (= forage) (t/ha)	1.85	3.43
Total pasture yield = consumed + cut (t/ha)	6.03	2.95
Concentrate intake (t/ha)	1.48	1.38
Forage intake (t/ha)	1.25	0.73
Total intake = pasture + concentrate + forage (t/ha)	6.91	4.33

5 GHG emissions from livestock of differing growth parameters/potential (rib fat EBV)

In contrast to Scenario 4, a legitimate comparison is within the steer trader/finisher system by comparing the effects of improved growth rates and growth efficiency on GHG emissions. This was investigated in Scenario 5 (Table 5a) where the effects of selecting animals for lower or higher growth efficiency were modelled and compared. Preliminary results from the Beef CRC Maternal Productivity project (Beef CRC, 2008) indicate that animals genetically higher for rib fat will ‘finish’ more quickly than those genetically lower for rib fat. These effects were used as the basis for the simulations by changing the Growth Efficiency parameter (Stock Module – Energy tab) to be 11 and 22% lower and higher than the base case (Scenario 5). This was done by changing the default figure for Growth Efficiency from 45% to 35% (22% decrease), 40% (11% decrease), 50% (11% increase) or 55% (22% increase), thereby hopefully simulating the effects of changing rib fat EBV.

Table 5a shows that using animals of lower growth efficiency resulted in an increase in N_2O emissions (up to 1.8% increase) and CH_4 respiration (up to a 10% increase) and up to 7.7% increase in total GHG emissions (N_2O + CH_4). This increase was while average steer weight gain and total steer carcase weight remained essentially unchanged (range from 264.6 to 255kg weight gain and 18,916 to 18,950 for carcase weight). Increasing growth efficiency had the converse effect of reducing N_2O emissions by up to 1.3%, CH_4 respiration by up to 6.4% and total emissions by up to 5%.

Table 5a: GHG emissions and animal production for rotationally grazed steers in a trader/finisher system at pasture with the effects on growth potential simulated (figures in brackets indicate the % change in the parameter compared to the ‘standard’ steer grazing scenario – Scenario 5).

	N_2O emissions	**CH_4 respiration**	**Total N_2O + CH_4**	**Production Data for the modelled ‘farms’**		
	t CO_2e/t carcase weight/year	t CO_2e/t carcase weight/year	t CO_2e/t carcase weight/year	Number of steers	Average steer weight gain (kg)	Total steer carcase weight gain (kg @ 55% dressing)
5a. 22% lower Growth Efficiency (changed from 45 to 35%)	3.39 (**1.8%↑**)	9.40 (**10%↑**)	12.79 (**7.7%↑**)	130	264.6	18,927
5b. 11% lower Growth Efficiency (changed from 45 to 40%)	3.35 (**0.7%↑**)	8.91 (**4.3%↑**)	12.27 (**3.3%↑**)	130	264.7	18,916
5. Standard rotationally grazed steer finishing	3.33	8.54	11.87	130	264.7	18,924
5c. 11% higher Growth Efficiency (changed from 45 to 50%)	3.29 (**1.1%↓**)	8.23 (**3.6%↓**)	11.53 (**2.9%↓**)	130	265.0	18,950
5d. 22% higher Growth Efficiency (changed from 45 to 55%)	3.29 (**1.3%↓**)	8.00 (**6.4%↓**)	11.28 (**5%↓**)	130	264.6	18,917

Table 5b shows that similar relatively small proportional changes in pasture intake (up to 5.9% increase and 4.5% decrease), concentrate intake (up to 3.6% increase and 1.4% decrease) and total intake (up to 9.2% increase and 5.8% decrease) to those indicated in Table 5a for GHG emissions. Total pasture growth increased by up to 9.2% with the lower growth efficiency and decreased by up to 5.8% with the higher growth efficiency simulations.

Table 5b: Pasture, concentrate and forage intake with the effects on growth potential simulated for steers in a trader/finisher system.

	Pasture intake	**% live intake**	**% dead intake**	**Total cut yield**	**Total pasture yield**	**Concentrate intake**	**Forage intake**	**Total intake**
	t/ha/year			t/ha	t/ha	t/ha	t/ha	t/ha
5a. 22% lower Growth Efficiency	2.35 **(5.9%↑)**	94.12	5.88	3.44	5.79 **(2.4%↑)**	1.43 **(3.6%↑)**	0.95	4.73 **(9.2%↑)**
5b. 11% lower Growth Efficiency	2.27 **(2.3%↑)**	94.00	6.00	3.43	5.70 **(5.9%↑)**	1.40 **(1.4%↑)**	0.83	4.5 **(4%↑)**
5. Standard rotationally grazed steer finishing	2.22	93.90	6.10	3.43	5.65	1.38	0.73	4.33
5c. 11% higher Growth Efficiency	2.17 (**2.3%**↓)	93.83	6.17	3.47	5.64 (**0.2%**↓)	1.37 (**0.7%**↓)	0.65	4.19 (**3.2%**↓)
5d. 22% higher Growth Efficiency	2.12 (**4.5%**↓)	93.82	6.18	3.49	5.61 (**0.7%**↓)	1.36 (**1.4%**↓)	0.60	4.08 (**5.8%**↓)

6 GHG emissions from livestock of differing growth parameters/potential (Net Feed Intake)

Another relevant comparison within the steer trader/finisher system is comparing the effects of improved feed efficiency on GHG emissions. This was achieved in Scenario 6 (Table 6a) where the effects of selecting animals for lower or higher Net Feed Intake (NFI or Residual Feed Intake (RFI)) were modelled and compared. These effects were modelled by changing the Maintenance Coefficient component (Stock Module – Energy tab) to be 6.2 and 6.3% lower and higher than the base case/default values (changed from 0.48% to either 0.45 or 0.51%).

The reduction in efficiency (higher Maintenance Coefficient) resulted in only very minor changes to N_2O emissions (0.9% increase), a 5% increase in CH_4 respiration and a 3.8% increase in total GHG emissions (Table 6a). Higher efficiency steers (lower Maintenance Coefficient) resulted in a 1% decrease in N_20 emissions, a 5.2% decrease in CH_4 respiration and a 4% decrease in total GHG emissions. Both of these scenarios occurred with essentially no change in steer weight gain (range: 264.7-265 kg) or total steer carcase weight gain (range: 18,916-18,950kg; Table 6a).

Table 6a: GHG emissions and animal production for rotationally grazed steers in a trader/finisher system at pasture with the effects on maintenance energy requirements simulated (figures in brackets indicate the % change in the parameter compared to the 'standard' grazing scenario – Scenario 6).

	N_2O emissions	CH_4 respiration	Total N_2O + CH_4	Production Data for the modelled 'farms'		
	t CO_2e/t carcase weight/year	t CO_2e/t carcase weight/year	t CO_2e/t carcase weight/year	Number of steers	Average steer weight gain (kg)	Total steer carcase weight (kg @ 55% dressing)
6a. Lower efficiency (Maintenance Coefficient changed from 0.48 to 0.51%)	3.36 (**0.9%↑**)	8.97 (**5%↑**)	12.33 (**3.8%↑**)	130	264.2	18,888
6. Standard rotationally grazed steer finishing	3.33	8.54	11.87	130	264.7	18,924
6b. Higher efficiency (Maintenance Coefficient changed from 0.48 to 0.45%)	3.30 (**1.0%↓**)	8.10 (**5.2%↓**)	11.40 (**4%↓**)	130	264.7	18,929

Table 6b shows that the relatively small changes in GHG emissions coincided with only small changes in total pasture yield (0.9% increase and 2.5% decrease) and concentrate intake (2.2% increase and 0.7% decrease) and slightly larger effects on pasture intake (5% decrease/3.6% decrease) and total intake (4.6% decrease/4.6% increase).

Table 6b: Pasture, concentrate and forage intake with the effects on maintenance efficiency simulated for steers in trader/finisher system.

	Pasture intake	% live intake	% dead intake	Total cut yield	Total pasture yield	Concentrate intake	Forage intake	Total intake
	t/ha/year			t/ha	t/ha	t/ha	t/ha	t/ha
6a. Lower efficiency (Maintenance Coefficient changed from 0.48 to 0.51%)	2.30 (**3.6%↑**)	94.15	5.85	3.49	5.79 (**2.5%↑**)	1.41 (**2.2%↑**)	0.82	4.53 (**4.6%↑**)
6. Standard rotationally grazed steer finishing	2.22	93.90	6.10	3.43	5.65	1.38	0.73	4.33
6b. Higher efficiency (Maintenance Coefficient changed from 0.48 to 0.45%)	2.11 (**5%↓**)	93.95	6.05	3.59	5.70 (**0.9%↓**)	1.37 (**0.7%↓**)	0.65	4.13 (**4.6%↓**)

6A Putting it all together - GHG emissions from livestock of differing growth parameters/potential (rib fat and Net Feed Efficiency)

A final comparison within the steer trader/finisher system was made to investigate the additive effects of improved growth efficiency AND improved feed efficiency (decreased NFI) on GHG emissions. This was carried out in Scenario 6A (Table 6c) where the effects of selecting animals for higher Growth Efficiency (22% higher than 'standard' – by adjusting Growth Efficiency from 1.3 to 1.5% - to simulate selection for higher rib fat EBV) and lower Maintenance Coefficient (from 0.48 to 0.45 - to simulate an increase in Net Feed Intake) [Stock Module – Energy tab] were modelled and compared.

Table 6a shows that this scenario resulted in only a small decrease in N_2O emission (2.1-2.2%) and a larger decrease in CH_4 respiration (11.3%). This was while average steer liveweight gain remained identical and there was only a minimal change in total steer carcase weight (34,407 vs 34,414 kg). This compares to a 1.3% reduction in N_2O emissions for Growth Efficiency only (Table 5a) and 1% for Maintenance Coefficient only (Table 6a) and 6.4 and 4% decreases in CH_4 respiration, respectively. The combined effects were a reduction of 8.8% in total GHG emissions (N_2O + CH_4) compared to 5% for Growth Efficiency only and 4% for Maintenance Coefficient only.

Table 6c: GHG emissions and animal production for a standard steer trading/finishing system simulation compared to one in which both growth efficiency and feed efficiency are enhanced.

	N_2O emissions		**CH_4 respiration**		**Total N_2O + CH_4**	
	'Standard' Steer trading	+ growth efficiency & maintenance efficiency	'Standard' Steer trading	+ growth efficiency & maintenance efficiency	'Standard' Steer trading	+ growth efficiency & maintenance efficiency
GHG emission per hectare (t CO_2e/ha/year)	0.63	**0.62 (2.1%↓)**	1.62	**1.43 (11.3%↓)**	2.25	**2.05 (8.7%↓)**
GHG emission per steer (t CO_2e/steer/year)	0.48	**0.47 (2.1%↓)**	1.24	**1.10 (11.3%↓)**	1.73	**1.58 (8.7%↓)**
GHG emission per kg live product (t CO_2e/ t steer liveweight gain/year)	1.83	**1.79 (2.2%↓)**	4.70	4.17 **(11.3%↓)**	6.53	**5.96 (8.8%↓)**
GHG emissions per kg steer carcase weight (t CO_2e/t steer carcase weight/ year)	3.33	**3.26 (2.2%↓)**	8.54	7.57 **(11.3%↓)**	11.87	**10.83 (8.8%↓)**
			'Standard' Steer trading		**+ rib fat & low NFI**	
Production data for the modelled 100ha 'farms'	Number steers		130		130	
	Average steer liveweight gain		264.7kg		264.7	
	Total steer liveweight gain		34,407kg		34,414kg	
	Total steer carcase weight gain		18,924kg (at 50% dressing)		18,928kg (at 55% dressing)	

Table 6d shows a very minor reduction in total pasture yield (0.7%), a slightly lower concentrate intake (3.6%) and substantially lower pasture intake (8.6%), forage intake (28.8%) and total intake (10.6%), while animal growth was maintained (Table 6c) and N_2O and CH_4 also decreased.

Table 6d: Pasture, concentrate and forage intake for a standard steer trading/finishing system simulation compared to one in which both growth efficiency and net feed efficiency are enhanced

	Standard Steer/trader	Enhanced	% change
Pasture intake (t/ha/year)	2.22	2.03	8.6%↓
% live intake	93.90	93.74	0.2%↓
% dead intake	6.10	6.26	2.6%↑
Total cut yield (= forage) (t/ha)	3.43	3.58	4.4%↑
Total pasture yield = consumed + cut (t/ha)	5.65	5.61	0.7%↓
Concentrate intake (t/ha)	1.38	1.33	3.6%↓
Forage intake (t/ha)	0.73	0.52	28.8%↓
Total intake = pasture + concentrate + forage (t/ha)	4.33	3.88	10.6%↓

7 GHG emissions from high intensity rotational grazing (TechnoGrazing™)

It was not possible to adequately simulate a TechnoGrazing rotational grazing system with the SGS Pasture Model. This was in part due to the large number of paddocks and rotations necessary in the simulation, as well as that it would have been necessary to change many other parameters in the model in order to properly simulate a TechnoGrazing system such as run at Struan Research Centre

8 GHG emissions from high intensity rotational grazing and use of improved genetics/growth/rib fat EBV's

Again this simulation was not possible due to the complexity required to adequately simulate a TechnoGrazing system with the SGS Pasture Model.

DISCUSSION & CONCLUSIONS

1 Strengths and weaknesses of the two models/calculators

In the end this project was only able to look at the SGS Pasture Model in detail. Despite its complexity this model is clearly very powerful, having many parameters that can be modified and tested to see their effects on the array of outputs – soil, water, animal, pasture, etc. In fact, the number of parameters that can be altered is a significant strength of the model as it allows for many scenarios to be tested.

It is also important to note that the model produced results that were in line with other published data (e.g. Peters *et al.,* 2010 and Eady *et el.,* 2011 – using a Life Cycle Assessment approach; Browne *et al.,* 2011 – using GrassGro and the similar DairyMod), indicating that the model produces outputs that are within acceptable ranges from other modelled data.

The major weaknesses of the model are:

1. The necessary complexity means that the model is not always straight forward to use and requires at least a small amount of training (which is currently supported by Brendan Cullen at the University of Melbourne – this is a very useful resource) and a good deal of practice to use well.
2. In a cow/calf breeder simulation the CH_4 respiration of the calves at pasture is currently not included in the model outputs – B. Cullen (*pers. comm.*) noticed this anomaly and suggested an approach to overcome this significant weakness. This was that calf pasture intake was used to calculate their CH_4 respiration using the same formula as used in the model for the cows. These calculations were performed outside of the model using Microsoft Excel and the value was then added to that reported by the model.
3. There is difficulty running simulations of a trader/finisher operation – in order to obtain results for these farming systems it was necessary to run 10 individual year simulations, collate the data and then calculate means in Microsoft Excel rather than use outputs from the model, which were already averages over the simulation period (as was the case for the breeder operations over 61 years). This was not only time consuming and tedious but also has meant that the project only ran simulations for 10 years in the trader/finisher operations but 61 years for the breeder (cow/calf) operation. Although this solution was satisfactory it has undoubtedly led to results that are not truly comparable between the two systems due to the different background conditions that have resulted. For example, average rainfall for the 61 years of the breeder operation (1/1/1950 to 31/12/2010) was 557.35mm compared to only 513.64mm for the 10 years of the trader/finisher operation (1/1/2000 to 31/12/2010), which will undoubtedly have had other effects on pasture growth, nutrient turnover, etc.
4. A fourth significant weakness of the SGS Pasture Model was that it was not able to handle the complexity of a high intensity rotational grazing system such as the TechnoGrazing set up used at the Struan Research Centre. This was partly due to the large number of paddocks that would have been necessary to fully simulate the system (i.e. 100+ paddocks). The TechnoGrazing operation at Struan is also a trading/finishing system and the limitations of the model here have already been discussed (above). An initial attempt to simulate

TechnoGrazing was made during a model training session, however it appears that the capability of the model was exceeded and it crashed.

5. A final weakness of the SGS Pasture Model identified in this project is that GHG emissions for replacement cows are not included in the trader/finisher system. This may be a methodology issue related to a biophysical model or IPCC methodology, however Browne *et al.* (2011) included replacement stock in their analysis (via Life Cycle Assessment). Inclusion of this factor could add up to 20% to emissions intensity, depending on the replacement rate of cows in the herd.

Despite these weaknesses, the SGS Pasture Model does produce simulation estimates for GHG emissions that are within the range of other published data. The real question that needs to be addressed is whether these emissions figures reflect those that are actually occurring in the field. This would necessitate extensive field measurements of N_2O emissions from pasture and CH_4 respiration of cattle under differing grazing and other management regimens.

2 General Discussion

As already mentioned, the SGS Pasture Model as used in this project produced greenhouse gas emissions values that were similar to other published data (Peters *et al.,* 2010; Browne *et al.*, 2011; Eady *et el.*, 2011). Nitrous oxide emissions in this study ranged from 0.37 to 0.63 t CO_2e/ha/year and 2.14 to 3.39 t CO_2e/t carcase weight/year for different animal types, grazing scenarios and animal growth parameters. Similarly methane respiration rates ranged from 1.43 to 2.68 t CO_2e/ha/year and 7.57 to 15.85 t CO_2e/t carcase weight/year and total GHG emissions ranged from 2.25 to 3.09 t CO_2e/ha/year and 10.83 to 18.61 t CO_2e/t carcase weight/year.

In the first scenario simulated in this project (British breed self-replacing breeder operation, continuous grazing; steer and excess/cull heifer progeny sold at ~250kg liveweight) the GHG emissions for N_2O and CH_4 compared favourably with those reported by Browne *et al.* (2011), who used the GrassGro biophysical model. They report a range of 14.6 to 15.6 t CO_2e/t Primary Product (carcase weight of beef) for CH_4 emissions, compared to the values in Table 1 of 15.28 t CO_2e/t calf carcase weight. Similarly their values for total GHG emissions (N_2O + CH_4) range from 22.4 to 22.8 t CO_2e/t product compared to the values above of 18.61 t CO_2e/t calf carcase weight. Given that Browne *et al.* (2011) also achieved higher carcase weights than simulated in this project (183.0 vs 128.3 kg here) and were basing their simulations on benchmarking data from the Farm Monitor Project in Victoria – which were for average and the top 20% of farms in this state-wide benchmarking dataset - it appears that the values reported here are within the ‘normal’ range and are a good indication of the level of GHG emissions that could be expected from a British breed breeder operation with low pasture utilisation (continuous grazing) in the mid to lower South East of South Australia.

The second scenario simulated (British breed self-replacing breeder operation; rotational grazing; steer and excess/cull heifer progeny sold at ~250kg liveweight) was a direct comparison to the first, except that grazing management was changed from continuous to a rotational system. This scenario is therefore indicative of an increase in pasture utilisation from the generally low levels typical in the South East of South Australia (McFarlane, 2002). Again the results reported here (Table 2a - 15.85 t CO_2e/t calf carcase weight/year for CH_4 respiration and 18.28 t CO_2e/t calf carcase weight /year for total GHG emissions) are close to the range reported by Browne *et al.* (2011). Of greater significance, however is that the change from continuous to rotational grazing resulted in a large decrease in N_2O emissions (27%), a slight increase in CH_4 respiration (3.8% - from 15.28 to 15.85 t CO_2e/t calf carcase weight/year) and only a 1.8% decrease in total GHG emissions overall. These effects are most likely the result of:

- Better pasture utilisation under rotational grazing – 3.81 t/ha/year of pasture was consumed and 2.21 was conserved as forage under rotational grazing (Table 2b) and more of the pasture was eaten live rather than allowed to senesce and be consumed as dead pasture (95% vs 89% for continuous grazing). Both of these factors may have contributed to the lower N_2O emissions due to lower pasture wastage.
- Improved overall feed quality with rotational grazing – as already indicated, live pasture was 95% of the pasture intake under rotational grazing compared to 89% under continuous grazing; 18% more concentrate and 118% more forage (conserved pasture) were also fed under rotational grazing. These factors would all have contributed to improved calf growth rates under rotational grazing and thereby probably resulted in faster growth to weaning.
- The 3.8% increase in CH_4 respiration under rotational grazing was virtually matched by a 3.5% increase in total intake (6.21 vs 6.0 t/ha).
- There was also 37% more pasture grown under rotational grazing

This final point indicates that this relatively simplistic comparison of simulations of continuous and rotational grazing is not fully capturing all of the potential pasture and animal benefits of rotational grazing. For this reason a series of enhanced rotational grazing scenarios were then simulated in Scenarios 3a to 3c - incorporating improved animal growth, increased stocking rate and a reduced time to weaning. When improved animal growth and improved animal growth plus increased stocking rate were added to the simulation there was a substantial decrease in N_2O emissions (35.5 and 35.7%, respectively - down to 2.15 t CO_2e/t calf carcase weight/year) and CH_4 respiration (6.4 and 7.1%, respectively - down to 14.19 t CO_2e/t calf carcase weight/year) and therefore also a substantial decrease in total GHG emissions (12.2% - down to 16.33 t CO_2e/t calf carcase weight/year). There was also a substantial increase in total calf carcase weight produced (22.7%). These results clearly indicate that GHG emissions can be greatly reduced by incorporating a rotational grazing system AS LONG AS other changes are also made in the production system to fully capture the benefits – i.e. through improved animal growth and increased stocking rate. In these simulations this was also achieved with an increasing level of animal product produced (i.e. calf carcase weight), although in a carbon accounting/trading system this would most likely necessitate running the same number of animals on a smaller area of the farm, thereby opening up other production or GHG mitigation/offset options for the farm, such as tree planting.

The final scenario tested within the breeder operation was to reduce the time to weaning to better account for the effects of improved calf growth due to better pasture quantity and quality. The data for this scenario were slightly counter-intuitive as they did not result in a further decrease in GHG emissions, however this appears to be due to the model not being adequately able to account for these changes. This scenario probably needs a whole farm approach to determine any significant effects (e.g. perhaps using the FarmGAS Calculator) since there are a number of other factors that are happening at once. For example, with the calves being weaned earlier (at a lighter weight) there is then the likelihood that there will be a knock-on effect on cow and subsequent calf productivity due to more feed being available for the cows to get back into optimum calving condition. This indicates that many of the simulations undertaken in this project may have quite complex outcomes and therefore interpretation should be made with extreme care!

When a British-breed trader/'finisher' operation under rotational grazing (buying steers at ~250kg; growing to 550-600kg for slaughter) was simulated (Scenario 4) it was again evident that the GHG outputs were generally similar to those reported from other studies. Browne *et al.* (2011) indicates GHG emissions of 3.91-4.81 t CO_2e/ha compared to only 2.25 t CO_2e/ha in this study. Interestingly the figures on a per t of product basis (kg carcase weight) are substantially different (6.3-6.7 t CO_2e/t carcase weight for Browne *et al.* compared to 11.87 in this study), however this result may be due to differences in calculation methods between the studies (e.g. these simulations resulted in 145kg Hot Standard Carcase Weight gained and steer weights of 516kg compared to 327-344kg steers in the study by Browne and colleagues). Scenarios 5, 6 and especially 6A, where enhancements were made to the animal system in the simulations, show that the 'best' production system in GHG emissions terms produced total emissions of 10.83 t CO_2e/t carcase weight/year (and 2.05 t CO_2e/ha) – made up of 3.26 t CO_2e/t carcase weight/year as nitrous oxide and 7.75 t CO_2e/t carcase weight/year as methane.

In a similar manner to the additional cow/calf breeder operation simulations above (Scenarios 3 a, b & c), additional simulations of the trader/'finisher' operation were undertaken to determine the effects of a number of animal manipulations on GHG emissions (Scenarios 5, 6 & 6A). The first of these was the effect of increasing genetic fatness, as measured by rib fat, by manipulating the Growth Efficiency parameter in the SGS Pasture Model. Despite substantial changes to this parameter (11 and 22% lower or higher) there was no real difference in live or carcase weights turned off when either lower or higher rib fat animals were added into the simulations. There were, however moderate changes in GHG emissions (up to 7.7% increase and 5% decrease), which were at least partly explained by the effects on total dry matter intake, which increased by up to 9.2% (i.e. lower Growth Efficiency = higher total DM intake). The take home message from these simulations and comparisons is that lowering animal Growth Efficiency in the SGS Pasture Model (by inference due to lowering the level of genetic rib fatness) results in an increase in GHG emissions (mainly due to an increase in methane respiration), which is also associated with a concomitant increase in dry matter intake. Conversely, increasing animal Growth Efficiency (i.e. higher genetic rib fatness) results in a decrease in GHG emissions along with an associated decrease in dry matter intake.

When the effects on GHG emissions of altering the efficiency of feed conversion (expressed as Net Feed Intake or NFI) were simulated (Scenario 6), there were again moderate changes (~4%) in GHG emissions (especially CH_4 respiration) despite no real differences in live or carcase weights turned off. The changes in GHG emissions were therefore a consequence of changing the metabolism of the simulated animals resulting in changes to pasture intake (4.6% decrease in intake and 4% decrease in GHG emissions; 4.6% increase in intake and 3.8% increase in

GHG emissions). Thus, improved feed conversion efficiency (through differences in Net Feed Intake (NFI) but simulated through altering the Maintenance Coefficient in the model) DOES alter GHG emissions, however the changes are relatively small.

The final scenario tested was to determine if there were additive effects from incorporating both Growth Efficiency (carcase fatness) and feed conversion efficiency (NFI) effects in a trader/'finisher' operation (Scenario 6A). Table 6c shows that there were additive effects of these two factors, with GHG emissions being 8.8% lower than the base level scenario first tested (Scenario 5) when both modifications were made in the SGS Pasture Model. These effects were largely due to a large decrease in CH_4 respiration (11.3%), which was matched by a 10.6% reduction in total DM intake (Table 6d). Interestingly the magnitude of these reductions was similar to the total changes from improving and taking full benefit of rotational grazing in the cow/calf breeder operation. It could therefore be concluded that, at least as far as simulation modelling is concerned, improving pasture utilisation (through rotational grazing) and improving growth and maintenance efficiency of livestock have a similar effect on reducing GHG emissions. That is, they may be alternative strategies that could be used, but also could be additive strategies that may result in even greater reductions?

It is important to note that direct comparisons should not be made between the outputs from the cow/calf breeder operation and the steer trader/'finisher' operation in this study. This is because the trader/'finisher' operation does not include any maintenance requirements or GHG emissions of the cows producing the steers for finishing while the breeder operations include the higher ME requirements associated with lactating and pregnant animals. These comparisons are therefore better made using Life Cycle Assessments such as those used by Peters *et al.* (2010) and Eady *et al.* (2011) or perhaps more appropriately by including lifetime emissions from the bought stock, as suggested by Browne et al. (2011).

(high intensity rotational grazing) using the SGS Pasture Model. Although this was partly due to a weakness of the model (i.e. not being able to handle the number of paddock rotations required) it was also a consequence of how the simulations and scenarios were run in this study. The TechnoGrazing system at Struan Research Centre, on which the simulations would have been based, is used on a seasonal basis to maximise the utilisation of the high spring pasture growth rates while also maximising animal (particularly bull) growth rates. In order to simulate this operation it would have been necessary to make a number of changes to the model parameters, thereby making comparisons to the other simulations difficult. For example, it would have been necessary to:

i. Change the simulations to a different time of year for pasture growth and grazing – the breeder and finisher systems (above) were simulated over a calendar year whereas the dryland TechnoGrazing systems at Struan are generally run from June to December or January.

ii. Set up different initial pasture conditions (green pasture in mid winter vs dry pasture on Jan 1 as has been simulated for other scenarios)

iii. Set up different initial soil conditions to account for differences that naturally arise at this time of the year (e.g. moist soil; different nutrient levels and nutrient cycling)

iv. Simulate short term animal growth only – to simulate the trader/finisher scenario with bulls

The result is that this would be a very different system to the others simulated for the steer trader/finisher system (and even more so to the breeder system) and comparisons to these would therefore have been very difficult.

Final Discussion/Conclusions

The simulations run for this project resulted in greenhouse gas emissions that were similar to those reported from other studies, particularly the similar study by Brown *et al.* (2011). For example, this study resulted in a GHG intensity of 16.33 to 18.61 t CO_2e/t calf carcase weight for a British-breed self replacing breeder operation, compared to a range from 22.4 to 22.8 t CO_2e/t carcase weight in the study by Browne and colleagues. The breakdown of GHG emissions was also similar, with Browne et al. (2011) showing methane respiration of 14.6-15.6 t CO_2e/t carcase weight compared to 14.19 to 15.28 t CO_2e/t calf carcase weight in this study (86.9% of emissions by Browne and co-authors compared to 82.1% in this study).

In contrast, this study produced much higher GHG emissions for trader/finisher cattle systems than those of Browne *et al.* (2011) – 6.3 to 7.7 t CO_2e/t steer carcase weight by Browne *et al.* compared to 10.83 to 12.79 t CO_2e/t steer carcase weight in this study, although liveweights and production systems were also markedly different between the two studies.

Within the self replacing breeder operations compared in this study the results indicate that 'simply' changing from a continuous grazing (or set stocked) to a rotational grazing system will result in a minor reduction (1.8%) in total GHG emissions, apparently driven by an improvement in pasture utilisation and a reduction in pasture wastage. If, however there is a planned attempt to capture many of the likely pasture effects of rotational grazing (i.e. more pasture grown, more pasture utilised, increased pasture quality and therefore increased overall diet quality) by increasing both animal growth rate and stocking rate, total GHG emissions can be reduced by 12.2% while also increasing the total amount of product produced (calf carcase weight). Again this effect is driven by a large decrease in nitrous oxide emissions (36%), presumably due to less pasture wastage. However a 7% reduction in methane respiration by the cows and calves in the simulations was also a significant contributor, due (presumably) to the improved nutritional quality of the pasture and the overall diet quality.

In the trader/finisher operations simulated in this study the effects of introducing less or more efficient animals into the production system resulted in increasing (lower growth efficiency) or decreasing (higher growth efficiency) total GHG emissions due to changes in dry matter intake by the animals. It is expected that these results are in line with those that would result if the genetic fatness of the animals was manipulated. Similarly, manipulation of feed efficiency resulted in the expected effects of increasing total GHG emissions when the maintenance efficiency of the animals was decreased and increasing total GHG emissions when it was increased. Moreover, when both growth and feed efficiency effects were applied at the same time there was a large reduction in total GHG emissions (up to 8.8% in this study). Thus it appears that increasing growth and/or feed efficiency are viable ways for livestock producers to reduce the GHG emissions from their livestock enterprises.

In conclusion, the simulations undertaken in this study and reported here indicate that GHG emissions can be reduced in a range of beef production systems in pasture-fed situations in South Eastern South Australia by improved grazing management and genetic selection of more efficient animals. The significant question that remains from this work however is whether these modelled results would be translated into actual measured differences in the field. It is therefore extremely important to obtain actual field measurements of GHG emissions in the situations simulated in this study as these data will be vital to demonstrate to livestock producers the potential of manipulations such as tested here since they are often very wary of modelling results. The project has also indicated a number of weaknesses with the main model used, the SGS Pasture Model, particularly when trying to simulate a high intensity grazing system such as the TechnoGrazing system used at Struan Research Centre.

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