Research Stimulus Fund

Final Report

'Reducing greenhouse gas emissions in beef production systems'

DAFF Project Ref No: RSF 05-224
Start date: 01-03-2006
End date: 28-02-2010

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Please tick below the appropriate area on the research continuum where you feel this project fits

BASIC/FUNDMENTAL    APPLIED/PRE COMMERCIAL

√

Key words: Cattle, greenhouse gas, feed efficiency
1. **Rationale for Undertaking the Research**

Increases in atmospheric concentrations of GHG are considered a likely cause of global warming. In Ireland, 29% of our national emissions derive from agriculture, a much higher proportion than occurs in other northern European countries. Since enteric methane produced by ruminants (predominantly cattle) contributes about half of the GHG output from Irish agriculture, mitigating methane output has been the focus of considerable research.

A recent review of on-farm level modelling approaches, it was concluded that a whole-farm approach is a powerful tool for the development of cost-effective GHG mitigation options, as relevant interactions between farm components are revealed. The acceptability of alternative production systems from a farmer’s perspective will be predicated by the impact of these systems on farm profitability. The generation of such a resource for the Irish beef industry as well as the identification of beef cattle farming systems which are most sustainable from both GHG emissions and farm profit viewpoints were key aims of Task 1 within the current project.

As stated above, enteric methane (CH\(_4\)) from ruminant animals is a considerable contributor to global warming and thus there is current interest in the identification of viable farm-level mitigation strategies. Selection for improved feed efficiency in beef cattle, measured as residual feed intake (RFI) has been proposed as a potentially novel approach to reducing CH\(_4\) emissions without compromising animal production (Hegarty et al., 2007). However, although there is some evidence for reduced CH\(_4\) from energetically efficient animals there is no published information on whether the effect is consistent across different diet types. The aim of the studies conducted as part of Task 2 of the current project was to examine the effect of divergent phenotypic selection for RFI, as well as diet type, on ruminal CH\(_4\) emissions, diet nutrient digestibility and on indices of ruminal fermentation in beef cattle. Because acceptability by producers of any potential mitigation strategy will rely on its knock-on effects on key economically relevant traits, these were examined as part of this project. Furthermore, due to the imminent progression within the Irish cattle breeding programme towards genomically assisted selection, we endeavoured to examine some of the key genes affecting feed efficiency in cattle. Finally, as a consequence of its fundamental role in not alone feed digestion but also methanogenesis, we conducted a number of novel studies to explore the effects of feed efficiency as well as diet type on the ruminal metagenome.

Diets that provide cattle with an increasing proportion of starch (e.g. maize silage harvested at a more advanced growth stage, whole-crop wheat silage of higher grain content, barley grain fed to appetite) are predicted to reduce methane emissions and increase animal growth rate, thereby reducing emission intensity (i.e. kg CO\(_2\)e/kg carcass gain; CO\(_2\)e is the amount of carbon dioxide that has an equivalent global warming potential as the net amount of carbon dioxide, methane and nitrous oxide released as part of the
beef production system). What is unclear is the extent of these effects, the relativity between contrasting feeds and what the overall outcome might be as assessed by a life-cycle assessment. All of these issues were addressed as part of the third Task conducted within this project with all data published in international scientific journals.

2. **Research Approach**

Specify the research methodologies employed, emphasising novel techniques and also outline any modifications from the original approved project proposal.

This project utilised a number of existing and novel methodologies to address the research questions of interest. In particular, in all three Tasks new methodologies/tools not previously established within the research team, were developed.

In Task 1, A novel whole farm stochastic BEEF systems Greenhouse gas Emissions Model (BEEFGEM) was developed through the merging and redevelopment of the existing Grange beef systems economic model and a dairy systems GHG emissions model. In order to increase the dynamism and predictive capacity of the model, stochastic modelling technology, not initially envisaged in the original RSF application was employed. The BEEFGEM has been further developed, as described below, and is currently being used for the benefit of the Irish beef industry as part of a Bord Bia funded initiative to capture the carbon footprint of Irish beef.

In Task 2 a range of traditional and state-of-the-art scientific approaches were used to examine the physiological and biochemical control of energetic efficiency in cattle. Advanced molecular based technologies were used to determine effects of both animal energy efficiency capacity, together with diet type on the ruminal microbiome and metagenomic (functional capacity). The suite of whole farm stochastic BEEF systems Greenhouse Gas Emissions Model (BEEFGEM) tools available to us towards the end and subsequent to the completion of this project were beyond those originally available and/or envisaged. Indeed through additional funding from Teagasc, two new offshoot projects were designed and are currently in progress which will use cutting edge technologies such as high throughput nucleic acid sequencing technology to characterise gene and protein expression profiles in both tissue and the digesta of cattle divergent for energetic efficiency. The strong linkages, outlined in the various progress reports, developed with international research groups and in particular in the University of Alberta, Edmonton, Canada, together with the high quality scientific publications generated from this task, have greatly increased the visibility of our work to the global scientific audience.
3. Research Achievements

The aim of Task 1 was to investigate the effect of alternative production systems at farm level on GHG emissions. Greenhouse gas emissions were modelled for five contrasting beef production systems, one based on average farm conditions in Ireland and four based on research farm conditions. Both direct and total GHG emissions per hectare increased with increasing stocking rate for all scenarios tested. However, increasing stocking rate led to a reduction in GHG emissions per kg beef carcass, albeit with higher levels of production efficiency. At moderate stocking rates, increasing stocking rate further resulted in an increase in GHG emissions per kg beef carcass. Cattle production systems finishing males as bulls had lower GHG emissions than production systems finishing males as steers and thus, the lowest GHG emissions per kg beef carcass were achieved for bull beef production systems at moderate stocking rates which had direct and total system GHG emissions of 15.7 and 18.9 kg CO₂e/kg beef carcass, respectively. Bull beef production systems at high stocking rates were most profitable. The highest GHG emissions were for the scenario representing average farm conditions in Ireland with direct and total emissions of 19.0 and 23.1 kg CO₂e/kg beef carcass, respectively. This was also the least profitable scenario.

As part of Task 2 a series of studies which examined (i) the physiological and genomic control of feed/energetic efficiency in beef cattle and (ii) the effect of feed efficiency, as well as diet, on GHG gas emissions and the ruminal microbial environment were conducted. Overall, energetically efficient (low RFI; RFI was < -0.5 SD below the mean) bulls and heifers consumed up to 16% less feed daily for the same level of growth and carcass composition as their inefficient counterparts (high RFI; RFI was >0.5 SD above the mean). Repeatability estimates were moderate to high for energetic efficiency and related traits. This work also provided evidence of an association between cellular mitochondrial biogenesis and energetic efficiency and the findings could ultimately be used in the identification of genetic markers, following appropriate validation, for the identification of cattle that are more economically and environmentally sustainable to produce.

The second aim of this task was to examine the effect of divergent phenotypic selection for RFI, as well as diet type, on ruminal CH₄ emissions, diet nutrient digestibility and on indices of ruminal fermentation in beef cattle. Ruminal CH₄ emissions were measured using the sulphur hexafluoride (SF₆) tracer gas technique on three sequential occasions as follows: (i) at the end of a six week period on grass silage (GS); (ii) following an eight week period at pasture (GG) and (iii) at the end of a five week period on a 0.3:0.7 maize silage:concentrate total mixed ration (TMR). There was no evidence for a RFI phenotype x diet interaction for DMI. This work concluded no difference in DMI between H and L RFI animals across the three diets fed. Ruminal CH₄ emissions and the digestibility of some dietary fractions were affected by the contrasting diet types offered. The data also suggest that differences in digestive capacity for some dietary fractions but not ruminal CH₄ production, may contribute to differences in RFI between cattle.

A follow on programme of work, which employed the same animal population, examined the effect of phenotypic divergence in feed efficiency, measured as residual feed intake, on the ruminal microfloral population of beef heifers while offered (i) a low
energy, high forage (HF) diet followed by (ii) a high energy, low forage (LF) diet. This study used a combination of (i) polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE) to profile the overall rumen bacterial community; (ii) quantitative polymerase chain reaction (qPCR) to quantify key rumen microbes. (iii) next generation 454-pyrosequencing to more accurately profile the entire ruminal microbiome. Collectively, these studies suggest that a core group of bacteria and methanogens occupy the rumen and that the association of rumen microbes with RFI ranking is likely to be modulated by the type of diet offered. Ongoing work follow-on work is examining not only the abundance of different classes of microbes but also their potential functional capacity.

The objective of the research conducted for the third task of this project was to investigate the effect of various ensiled feeds on ruminal methanogenesis in beef cattle. An experiment was carried out to quantify the methane emissions, feed intake, performance and dietary digestibility of finishing beef cattle offered diets based on maize silages harvested at four different stages of maturity, and ranked these relative to an ad libitum concentrates based-diet (ALC). Methane emissions (g/d), measured using the SF₆ tracer technique, were not affected by maize harvest date, however emissions per unit of DM intake (DMI) and carcass gain tended to decrease with advancing maize maturity at harvest. Cattle offered ALC exhibited lower methane emissions than those offered maize silage-based diets. In a second experiment, increasing the grain content of whole crop wheat (WCW) silage decreased methane emissions per unit of DMI or carcass gain. Cattle offered GS had highest and those offered ALC lowest methane emissions per unit of DMI. A further study assessed the methane output associated with a range of feeds including high moisture grains, and maize and WCW silage, using the total gas production (TGP) technique. It was concluded that the TGP technique did not provide sufficiently reliable estimates of trends observed in vivo. The final study which was linked to the GHG modelling work conducted in Task 1 aimed to quantify the on-farm and total greenhouse gas (GHG) emissions associated with finishing beef production systems based on maize and WCW silages, GS and ALC. The GS scenario was more sustainable in terms of GHG emissions and financial performance than the maize, WCW or ALC scenarios.
4. Impact of the Research

Provide a summary of outcomes of research and outline the benefits of the research to end users, e.g. industry, consumers, regulatory authorities, and scientific community etc.

A number of initiatives of national economic importance were developed through information generated from this RSF project. These include:

(i) The development of the BEEFGEM

Since the development of the BEEFGEM Teagasc and Bord Bia have been working collaboratively to develop systems to “measure and reduce” GHG emissions from Irish beef farms. The objective was to develop an internationally accredited approach to audit GHG emissions from beef farms and consequently to put in place tools to enable farmers to identify management strategies to reduce emissions. The baseline model used in these initiatives is the BEEFGEM. The project has developed a methodology for “auditing” greenhouse gas emissions from Irish beef farms. This methodology has been accredited to ISO standards by the Carbon Trust. Approximately two hundred farmer participants in the Beef Quality Assurance Scheme participated in a pilot phase for the carbon audit project. The objective was to accurately measure GHG emissions of typical Irish beef production systems through appropriate sampling of a range of farm systems. In other words, the farms were selected so as to be representative of the range of beef farming systems found in Ireland. The methodology is unique in that it incorporates a number of data sources, including data from the Department of Agriculture and Marines' Animal Identification and Movements database and farm level survey data, to provide a detailed picture of the production systems and related activity on each farm. This detailed information when processed through the BEEFGEM model provides a comprehensive database of estimated total farm emissions and the relative strength of emission sources for Irish beef farms. The information gleaned from the Carbon Audit is a critical first step to identifying the most important production activity or emission source on beef farms where GHG emissions are large relative to other emission sources. It will also permit the across-farm comparison of the relative strength of the different emission sources for similar beef systems.

Carbon Navigator

In addition to estimating GHG emissions on beef farms, it is necessary to provide recommendations for the reduction (or mitigation) of these emissions. Teagasc and Bord Bia are currently (December 2012) developing a software program to assist farmers to identify the capacity to reduce GHG emissions and to achieve these reductions by setting targets for key aspects of their production system. This software program is called the Carbon Navigator and focuses on “distance to target” and “distance to best practice”. It will not be necessary to estimate total beef farm system GHG emissions to use this program; it aims to “cut” emissions rather than “count” emissions. The Carbon Navigator provides an estimate of the potential of alternative strategies to reduce emissions based on current and projected future levels of productivity. The program focuses on mitigation options that are cost effective and in most cases improve farm profitability.
(ii) Best practice guide for CH$_4$ emissions from grazing animals
The co-ordinator is current co-authoring a best practice guide to CH$_4$ measurements using SF$_6$ tracer technique for distribution to all Alliance members Argentina, Australia, Brazil, Canada, France, Ireland, New Zealand, USA, UK which is due to be published in mid 2013. This initiative is part of the Global Research Alliance led by New Zealand and Drs. David Kenny and Padraig O’ Kiely became involved in this directly through their involvement in the current DAFM RSF project. Padraig O’ Kiely is the Irish representative on the Livestock Research Group of the Global Research Alliance.

(iii) Establishment of a Rumen Microbial Genomics Network
Researchers from Australia, Argentina, Canada, France, Ireland, Japan, New Zealand, UK, USA and the Netherlands are involved in an international project which aims to characterise the ruminal microbiome. This Network which is co-ordinated by New Zealand has been supplied with DNA from digesta samples collected as part of Task 2 of the current project as well as intellectual input from the research team. Again, our involvement in this large multi-national project of significant potential economic value stemmed directly through internationally published data emanating from work conducted for Task 2.

(iv) Development of Custom SNPChip
An Irish custom single nucleotide polymorphism (SNP) chip suitable for both beef and dairy cattle, called “International Dairy-Beef 19” (IDB19), was recently developed through collaboration between Teagasc, ICBF and the Irish Equine Centre and will be available commercially in early 2013. This resource is superior to other current commercially available low-density SNP panels. The objective of this initiative was to develop a single custom SNP chip for Irish dairy and beef cattle that can 1) impute from SNPs to microsatellites for parentage verification against animals with only microsatellite information, 2) screen for lethal recessives and genetic mutations with major effects, 3) improve imputation accuracy to high density SNP panels, and 4) provide an avenue to genotype a large population of animals for research mutations. Genes identified as being associated with improved feed efficiency in Task 2 of the current project, including those involved in cellular energetics as well as regulation of the somatotrophic axis were sequenced for SNP and these were integrated into the aforementioned SNP chip.

(v) A lifecycle analysis of GHG emissions from beef cattle finishing based on alternative forages
Greenhouse gas (GHG) emissions from finishing cattle systems reflect the dietary ingredients fed. Diets high in cereal grains increase growth rate and reduce enteric methane emissions compared to forage-based diets. A life-cycle analysis accounting for (a) direct and indirect GHG emissions (carbon dioxide, methane and nitrous oxide) from the cattle production system, (b) carbon sequestration under permanent grassland, and (c) carbon loss where grassland is replaced by cereals or maize, indicates that the beef from cattle finished on a grass silage-based diet had a lower emissions intensity (a.k.a. carbon
footprint; kg CO2e/kg carcass gain) than from a diet based on maize silage, whole-crop cereal silage or ad libitum concentrates.

The results of this analysis provide:

- Farmers with dietary and management strategies for simultaneously increasing profitability and reducing the emissions intensity of the beef they produce.
- Policy makers with the evidence that national GHG inventory systems must account for land use and land use change (LULUC) in addition to the more obvious direct and indirect emissions of GHG.
- Beef exporters with a marketing advantage for Irish beef produced from permanent grassland.

5. Exploitation of the Research

Outline the outcomes of the research that have commercial or economic importance and provide details of Intellectual Property / licences / patents generated. Details of outputs adopted by industry should also be provided.

A number of initiatives with national economic importance were developed through information generated from this RSF project. These include the development of the BEEFGEM as well as the Irish custom single nucleotide polymorphism (SNP) chip suitable for both beef and dairy cattle. These as well as other initiatives of potential economic importance are detailed in Section 4 above. The BEEFGEM in particular has huge potential to be adopted by industry and has been on a pilot basis as outlined earlier. Given the public good nature of the work conducted directly as part of this project as well as subsequent ancillary initiatives, no attempt, as yet, has been made to patent or license any of the outcomes.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents
   1. None
   2. 

(b) Innovations adopted by industry
   1. BORD BIA MODELLING
   2. Custom SNPChip

(c) Number of companies in receipt of information

(d) Outcomes with economic potential
   1. SNPCHIP
   2. 

(e) Outcomes with national/ policy/social/environmental potential
   1. BEEFGEM
2. Carbon Navigator

(f) Peer-reviewed publications, International Journal/Book chapters.


Papers ready to submit:


(g) Scientific abstracts or articles including those presented at conferences


(h) National Report

2. (i) Popular non-scientific publications

(j) Workshops/seminars/open days at which results were presented (excluding those in (g))


7. Public lecture organized by UCD Earth Sciences Institute, TCD TrinityHaus and Dublin City Council, under the TCD-UCD Innovation Alliance and in collaboration with Business in the Community and the main agencies involved involved in delivering policy (Comhar Sustainable Development Council, Enterprise Ireland, EPA, Geological Survey of Ireland, Marine Institute, Met Éireann, Sustainable Energy Authority of Ireland and Teagasc). The lecture ('Future opportunities to reduce bovine greenhouse gas emissions') given by Padraig O'Kiely can be accessed at [http://www.ucd.ie/earth/newsevents/transformingirelandseminarseries2010/seminar1160310/](http://www.ucd.ie/earth/newsevents/transformingirelandseminarseries2010/seminar1160310/)

### Permanent Researchers

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<th>Institution Name</th>
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<th>Total Time contribution (months)</th>
<th>Average time contribution per permanent staff member</th>
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<td>Teagasc</td>
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Total 7 42.6 6.15
8. Researchers Funded by RSF

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<td>Contract Researchers</td>
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9. Postgraduate Research

Total Number of PhD theses: 4

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date


Total Number of Masters theses: 1

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

10. Project Expenditure

Total expenditure of the project: €513,548.73

Total Award by RSF: €512,550

Other sources of funding (specify): €42,000
1. Teagasc Walsh Fellowship: €42,000

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11. Future Strategies

*Outline development plans for the results of the research.*

As discussed in detail in the preceding sections, the data generated in this project is/will be used as part of a number of national initiatives including the BEEFGEM, Carbon Navigator and the Irish customised SNPChip. Funding has been secured to continue our investigation into the biological control of energetic efficiency (Teagasc RMIS Project 6092; €350k) and the molecular control of the rumen microbiome during critical stages of the life cycle of cattle (Teagasc RMIS 6341; €341k).

The Principal Investigator recently secured an Ireland-Canada University Foundation Scholarship (€5k) to travel to the University of Alberta, Edmonton to learn about their ongoing research work and future plans in the area of feed efficiency and methane emissions of cattle, with particular emphasis around new initiatives they have developed to measure herbage intake at pasture. The successful procurement of this funding was exclusively due to data generated, and collaborative linkages established, as part of RSF 05-224. This trip will likely take place in April-May 2013.

12. Industry Collaboration

*Summarise details of industry collaboration in the research project.*

As outlined above significant industry collaboration has been established following completion of this project with An Bord Bia as well as with ICBF and Teagasc.