Department of Agriculture, Fisheries and Food
An Roinn Talmhaíochta, Iascaigh agus Bia

Research Stimulus Fund

Final Report

'Nutritional and Management Strategies to Reduce Nitrogen Excretion, Ammonia and Nitrous Oxide Emissions from Dairy, Beef and Pig Farms

DAFF Project Ref No: **RSF 07 536**
Start date: **01/12/2007**
End date: **01/02/2012**

Principle Coordinator: *Dr Karina Pierce, UCD*
Email:karina.pierce@ucd.ie

Other Principle Collaborating Researchers: *Drs Karl Richards and Gary Lanigan, Teagasc Johnstown, Prof J. O'Doherty, Drs T. Boland, B, Lynch, D. Kenny, G. Lanigan and T. McCabe, UCD.*

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

BASIC/FUNDMENTAL ——————→ APPLIED/PRE COMMERCIAL

	X	

Key words: *Nitrogen, ammonia, nitrous oxide, pigs, cattle, dairy cows*

NDP NATIONAL DEVELOPMENT PLAN

1. Rationale for Undertaking the Research

Losses of nitrogen (N) from agricultural production systems to the environment are of concern. Principally lost as ammonia (NH3) and nitrous oxide (N2O), these gases are deleterious to aquatic and terrestrial ecosystems and contribute to the greenhouse effect. Ireland, along with other countries has committed to reducing national emissions of these gases under the EU Climate and Energy Package (N2O, EU, 2008) and Gothenburg Agreement (NH3, S.I.244, 2006). As Irish agriculture and in particular, animal production contribute to large portions of national N2O (0.79) and NH3 (0.98) emissions, there is a requirement to examine strategies that reduce these emissions, of which dietary manipulation of N excretion offers great potential. In addition to gaseous losses, N can be lost to the environment as nitrate leachate ($NO3^-$), contributing to deterioration of estuarine ecosystems and drinking water quality. This project also examined the potential of dietary manipulation of urine N excretion on the fate of urinary N in the soil.

2. Research Approach

Experimental Task Numbers and Titles

Task 2. The effect of dietary manipulation on pig slurry and implications for grass growth and ammonia and nitrous oxide emissions following land application

Task 3. The effect of dietary crude protein on ammonia and nitrous oxide emissions from pig manure when spread on winter wheat at different growth stages

Task 4. The effect of dietary formulation with synthetic amino acids and fermentable energy sources on nitrogen excretion, ammonia and nitrous oxide emissions from autumn calving dairy cows

Task 4a. The effect of providing glucogenic or acetogenic diets on nitrogen retention, milk protein yield and mammary function in early lactation dairy cows

Task 5. The effect of dietary reformulation with lower protein concentrations, alternative energy sources and supplementary amino acids on nitrogen excretion by grazing dairy cows

Task 6. The effect of varying level of sucrose addition to perennial ryegrass diets on urinary N content, faecal nitrogen content, nitrogen excretion and ammonia and nitrous oxide losses from urine following land deposition

Task 7. The use of essential oils to reduce ammonia and nitrous oxide emissions from beef cattle

Task 8. Evaluation of nitrogen loss from land application of urine and slurry on micro plots at Johnstown Castle

The research reported herein utilises the combined knowledge of the pig, dairy, beef and crop production groups at University College Dublin to assess strategies that will reduce N losses from these production systems. There is a particular emphasis on dietary manipulations as these have the potential to improve N efficiency within the animal whilst reducing the quantity of N excreted, therefore reducing the environmental N burden. In addition, Tasks 2 and 3 evaluate new slurry application technologies and the effect of timing of pig slurry application to cereal and grass crops for their potential to reduce N2O and NH3 emissions. In Tasks 4, 4a and 5, dietary reformulation to reduce crude protein and balance the supply of amino acids were explored with a view to reducing N excretion from both the preserved forage fed and fresh grass fed lactating dairy cow. In Task 8 the effect of urine N content on nitrate leaching, nitrous oxide and di-nitrogen emissions was assessed using newly developed monolith lysimeters. This methodology deviated from the proposed suction cups and di-nitrogen was quantified instead of ammonia. This proved to be a better integrated method for quantifying nitrogen fluxes from urine patches. Cow urine was diluted or spiked with urea to ensure urine patches had N ranging from 300 to 1000 kg/ha. Urine was also spike with ^{15}N enriched urea to quantify di-nitrogen emissions and N mineralisation/immobilisation, which was one of the first times this approach was used at the lysimeter scale.

3. Research Achievements

Findings from this project show that manipulation of swine diets in the form of benzoic acid addition or reduction in dietary crude protein (CP) content reduces nitrogen (N) excretion and significantly, urinary nitrogen excretion. As a result of benzoic acid addition, reductions in ammonia and N20 emissions were reported also. Higher nitrous oxide (N2O) emissions were measured from manures produced by pigs fed a high CP diet with emissions reduced by 18% with the use of lower CP diets. Higher methane (CH_4) emissions were also measured from the high CP manure treatments. Timing of slurry application was

also of significance with ammonia losses at their highest when crop cover was low with total ammonical N losses accounting for 6-11% of total N applied.

Dietary manipulation of dairy cow diets to reduce environmental impact is possible without negatively impacting on milk yield and composition. Supplementary concentrate CP can be reduced from 190 to 150 g kg DM^{-1} during early lactation, without impacting on milk solids yield (1.85 kg day^{-1}). In fact, reducing CP content of the diet and increasing starch improved energy balance compared to higher CP lower starch diets. Urinary N excretion can be reduced by 25% where animals are offered the low CP concentrates. Blood urea N and BHBA concentrations were 23% and 17% lower respectively in animals offered low CP concentrates indicating a more favourable metabolic and N status could be achieved by reducing the CP of supplementary concentrates offered to pasture fed, early lactation dairy cows. Dietary addition of sucrose, fructose or condensed tannins did not influence urinary N, however impacts on milk composition were evident and merit further study. Results from this study are encouraging in terms of CH_4 mitigation for both allicin and capsaicin and further study is warranted.

Increasing the urine N application rate increased the cumulative amount of total N leached (inorganic & organic forms) and N2O emissions from this free-draining sandy soil type under high rainfall and drainage rates in the autumn-winter period. When the pasture was not growing, N leaching was the major loss pathway and thus an increasing quantity was leached as N inputs increased. There was a linear increase in N2O emissions with increasing urine N rate. Over both experimental years, the emission factors (EF3 values) for N2O from urine remained below 0.4% which is considerably lower than the IPCC default value of 2%.

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

This research and the publications arising from it, are extremely relevant given the significant issues around agriculture, slurry production, greenhouse and transboundary gases. The research also fills a knowledge gap in the area of slurry management and the

role that nutrition, combined with management of slurry, can play in reducing the impact of agriculture on the environment.

In many feeding situations producers continue to offer high crude protein diets resulting in excessive N excretion and potential for N loss the environment. The research in this project highlights the importance of diet formulation and timing of slurry application to reduce N losses to the environment. Importantly it showed that such dietary changes can be made without negatively impacting on animal performance. The research demonstrated the strong relationship between urine N content and both nitrate leaching and nitrous oxide emissions. The use of dietary manipulation could be an important mitigation measure for reducing both nitrate leaching and nitrous oxide emissions. In addition the N_2O emission factor <0.4% is considerably lower than the IPCC default value suggesting that soil type specific emissions factors would greatly improve the assessment of sustainable farm systems. It must be noted however, that where N excretion/emissions were reduced, a resultant reduction in CH4 was not always achieved and this has significant consequences for the adoptions of some of the strategies employed as a means of reducing the overall environmental impact.

For the indoor fed animal, formulating the diet to meet the requirements of production will help improve the efficiency of N use in the dairy cow. This will in turn reduce N excretion, urinary volume and the requirement for excreta storage over the housing period. Additionally, lower levels of urinary urea N excreted will reduce ammonia production associated with the storage and land spreading of excreta thereby reducing the impact of these activities on air quality.

Outcomes from this research include 3 PhD and 3 Masters theses, 9 full articles published in peer-reviewed high quality journals and 22 abstracts submitted to scientific conferences. The research outcomes also featured in a number of articles in the popular press and national reports. It is also important to note that all students registered with UCD are now in gainful employment either in Ireland or the UK.

The research in this project is useful commercially because it proves that the use of low CP feeds in pig and dairy diets can be employed without negatively impacting on animal

performance. In the case of the dairy cow, dietary CP can be reduced and energy balance in early lactation can be improved. The importance of timing of slurry application to reduce N losses to the environment is a key finding that can be employed by the industry also.

Some findings such as those in Tasks 6 and 7 provide valuable data and insight that can now be used by the scientific community for further studies in the areas of the role of essential oils in modifying the rumen microbial environment and also the implications of grass varieties on rumen fermentation and environmental impact.

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

The research in this project is useful commercially because it proves that the use of low CP feeds in pig and dairy diets can be employed without negatively impacting on animal performance. Reducing crude protein in animal diets will reduce the cost of feeding also. This approach is both acceptable to farmer and consumer because while reducing feed costs, the impact on the environment is simultaneously reduced thus improving the sustainability of animal production systems.
In the case of the dairy cow, dietary CP can be reduced and energy balance in early lactation can be improved at the same time. The importance of timing of slurry application to reduce N losses to the environment is a key finding that can be employed by the industry also.

There were no patents, licences or intellectual property generated during these tasks. However, reducing crude protein of diets does have an important impact on reducing costs of feeding dairy cows. In addition, from the data generated, appropriate advice was made available to industry via technical seminars and collaboration with Teagasc to allow adaption of these nutritional strategies into wider agricultural industry.

6. Summary of Research Outputs

(a) Intellectual Property applications/licences/patents

1. None

(b) Innovations adopted by industry

1. Use of low CP feeds in the diet of the dairy cow to reduce N excretion and improve energy balance in early lactation
2. Importance of timing of slurry application to reduce N losses to the environment and improve crop N uptake

(c) Number of companies in receipt of information

It is difficult to quantify the number of companies because company representatives were present in large numbers at many of the technical presentations given from researchers in the project over its lifetime. For example, information and advice on the results of Tasks 4, 4a and 5 have been disseminated at industry training days held at UCD Lyons Research Farm, the Agricultural Science Association Dairy Technical Seminar, the Alltech UCD Dairy Solutions Symposium, DSM technical conference in Dublin in 2012, and the Wageningen International Dairy Nutrition Symposium. Therefore, several national and international feed companies would have received the information generated from these tasks.

(d) Outcomes with economic potential

1. Use of low CP feeds in the diet of the dairy cow to reduce N excretion and improve energy balance in early lactation
2. Importance of timing of slurry application to reduce N losses to the environment

(e) Outcomes with national/ policy/social/environmental potential

1. Data from Task 4 demonstrated that crude protein levels of 140g kg DM^{-1} are sufficient to maintain milk production of 20 kg day^{-1} milk and 1.64 kg day^{-1} milk solids demonstrating that reasonable levels of milk production can be maintained without the need for excessive use of imported protein supplements. Additionally, these animals excreted a greater portion of nitrogen in the faeces compared to the urine. Given that faecal N is far less volatile than urinary N; strategies that increase faecal N at the expense of urinary N are environmentally advantageous. Finally,

reducing dietary crude protein intake will reduce the requirement for urea clearance from the blood, thereby reducing urine excretion, overall slurry volume and the requirement for winter storage.

2. Data from Task 4a showed that milk production can be maintained at 32 and 29 kg d^{-1} milk and 2.23 and 2.04 kg day^{-1} milk solids for diets containing 146 and 119 g CP kg DM^{-1} respectively. Moreover, the animals offered the lower CP diet had a more favourable energy balance during early lactation than those offered the higher CP diet. Improving energy balance in early lactation is important in maintaining the metabolic and health status of the dairy cow and may help improve persistency within the herd. This in turn will reduce the replacement rate on dairy farms allowing for increased milk production per unit of land and reduced environmental impact per unit of milk produced.
3. Data from Task 5 demonstrated that N excretion could be reduced in the pasture fed dairy cow through manipulation of the concentrate type offered. In this task, urinary N was reduced from 0.27 to 0.20 kg day^{-1} through reducing concentrate CP. The Intergovernmental Panel on Climate Change estimate that 0.02 of N excreted at pasture is lost as nitrous oxide. Therefore, the animals offered the lower CP concentrates will have a lower environmental impact compared to those offered the high CP concentrate. Furthermore, milk production (28.3kg day^{-1}) is maintained where the low CP concentrates are supplemented with methionine or where ground maize replaces rolled barley.

Task 8

1. Nitrous oxide emission factor 0.4 considerably lower than the current IPPC value of 2%.

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

Task 2

1. Murphy, D. P., J. V. O'Doherty, T. M. Boland, C. J. O'Shea, J. J. Callan, K. M. Pierce, and M. B. Lynch. 2011. The effect of benzoic acid concentration on nitrogen metabolism, manure ammonia and odour emissions in finishing pigs. Animal Feed Science and Technology. 163(2–4):194-199

Task 3

1. Meade, G., K. Pierce, J. V. O'Doherty, C. Mueller, G. Lanigan, and T. Mc Cabe. 2011. Ammonia and nitrous oxide emissions following land application of high and low nitrogen pig manures to winter wheat at three growth stages. Agriculture, Ecosystems and Environment 140(1–2):208-217

2. Meade, G., S. T. J. Lalor, and T. M. Cabe. 2011. An evaluation of the combined usage of separated liquid pig manure and inorganic fertiliser in nutrient programmes for winter wheat production. European Journal of Agronomy 34(2):62-70.

Task 4, 4a and 5

1. Whelan, S. J., F. J. Mulligan, B. Flynn, C. McCarney, and K. M. Pierce. 2011. Effect of forage source and a supplementary methionine hydroxy analogue on nitrogen balance in lactating dairy cows offered a low crude protein diet. Journal of Dairy Science 94(10):5080-5089.
2. Whelan, S. J., K. M. Pierce, C. McCarney, B. Flynn, and F. J. Mulligan. 2012. Effect of supplementary concentrate type on nitrogen partitioning in early lactation dairy cows offered perennial ryegrass-based pasture. Journal of Dairy Science 95(8):4468-4477
3. Whelan, S. J., K. M. Pierce, B. Flynn, and F. J. Mulligan. 2012. Effect of supplemental concentrate type on milk production and metabolic status in early-lactation dairy cows grazing perennial ryegrass-based pasture. J. Dairy Sci. 95(8):4541-4549
4. Whelan, S. J., F. J. Mulligan, B. Flynn, J.J. Callan and K. M. Pierce. 2012. Effect of forage source and a supplementary methionine hydroxy analogue on rumen fermentation parameters in lactating dairy cows offered a low crude protein diet. Animal Feed Science and Technology. in press
5. Whelan, S. J., F. J. Mulligan and K. M. Pierce. 2013. Nitrogen efficiency in contrasting dairy production systems. Advances in Animal Biosciences. In press.
6. Whelan, S. J., F. J. Mulligan, V. Gath, B. Flynn and K. M. Pierce. 2013. Dietary manipulation of crude protein and starch content affects energy balance in early lactation dairy cows. Journal of Dairy Science. In press

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

Task 2

D.M. Murphy, J.V. O'Doherty, K.M. Pierce, T.M. Boland, J.J. Callan and M.B. Lynch 2010. The effect of dietary benzoic acid concentration on nitrogen utilisation, manure ammonia and odour emissions in finisher pigs. *Proceedings of the Joint British Society of Animal Science/ Agricultural Research Forum, Belfast, Ireland*

Task 3

1. Meade, G., Pierce, K., O'Doherty, J.V., Mueller, C., Lanigan, G. & Mc Cabe, T. (2009). Ammonia and nitrous oxide emissions following land application of high and low nitrogen pig manures to winter wheat at three growth stages. Proceedings of the 60th Annual Meeting of the European Association for Animal Production, Barcelona, Spain, p559.
2. G. Meade, K.M. Pierce, C.Mueller, G. Lanigan, J.O' Doherty and T. McCabe. A field study on ammonia and nitrous oxide emissions following land-application of pig manure. Greenhouse Gasses and Animal Agriculture Conference 2010, Canada.
3. G. Meade, K.M. Pierce, C.Mueller, G. Lanigan, J.O' Doherty and T. McCabe. Measurement of greenhouse gas emissions of methane and nitrous oxide following hog manure application to winter wheat as affected by manure type and manure application timing. American Crop Science Conference 2010
4. Losses of nitrous oxide emissions following land application of high and low nitrogen pig manures to winter wheat at three growth stages. Climate for Change Conference, Dublin, 2010.
5. EAAP Conference Barcelona, Spain 2009.
   Meade, G, K. Pierce, J. V. O' Doherty, C. Mueller, G. Lanigan & T. Mc Cabe Ammonia and nitrous oxide emissions following land application of high and low nitrogen pig manures to winter wheat at three growth stages.

Task 4, 4a and 5

1. Whelan, S. J., F. J. Mulligan, J. J. Callan, and K. M. Pierce. 2010. The effect of forage source and supplementary rumen protected methionine on nitrogen balance in autumn calved dairy cows offered a low crude protein diet. in Proceedings of the British Society of Animal Science. British Society of Animal Science, Queen's University, Belfast, Northern Ireland.

2. Whelan, S. J., K. M. Pierce, J. J. Callan, and F. J. Mulligan. 2010. The effect of dietary crude protein, supplementary methionine and starch source on milk yield and composition in early lactation grazing cows. Page 396 in 61st Annual Meeting of the European Federation of Animal Science. Wageningen Academic Publishers, Heraklion, Crete, Greece.
3. Whelan, S. J., F. J. Mulligan, B. Flynn, and K. M. Pierce. 2010. The effect of forage source and supplementary rumen protected methionine on the efficiency of nitrogen use in autumn calving dairy cows. Page 396 in 61st annual meeting of the European Federation of Animal Science. Wageningen Academic Publishers, Heraklion, Crete, Greece.
4. Whelan, S. J., F. J. Mulligan, J. J. Callan, and K. M. Pierce. 2010. Effect of forage source and supplementary methionine on nitrogen balance and in-vitro ammonia emissions in dairy cows offered low crude protein diets. Page 105 in Climate for Change. Teagasc Publications, Dublin, Ireland.
5. Pierce, K. M., S. J. Whelan, J. J. Callan, and F. J. Mulligan. 2011. Effect of supplementary concentrate type on energy balance and blood metabolites in early lactation dairy cows offered grazed pasture. in ADSA-ASAS Joint Animal Meeting. Journal of Dairy Science, 94, E-Supplement 1, New Orleans.
6. Whelan, S. J., K. M. Pierce, B. Flynn, and F. J. Mulligan. 2011. Concentrate type affects nitrous oxide emissions from pasture based dairy production systems. Page 55 in Agricultural Research Forum 2011. Teagasc Publications, Offaly, Ireland
7. Whelan, S. J., K. M. Pierce, J. J. Callan, B. Flynn, and F. J. Mulligan. 2011. Supplementary concentrate type affects nitrogen balance in early lactation dairy cows offered grazed pasture. in ADSA-ASAS Joint Animal Meeting. Journal of Dairy Science, 94, E-Supplement 1, New Orleans.
8. Whelan, S. J., F. J. Mulligan, J. J. Callan, and K. M. Pierce. 2011. Effect of forage source and a supplementary methionine hydroxy analogue on rumen fermentation parameters. Page 80 in 62nd Annual Meeting of the European Federation of Animal Science. Wageningen Academic Publishers, Stavanger, Norway
9. Whelan, S. J., F. J. Mulligan and K.M. Pierce. 2012. Nitrogen efficiency in contrasting dairy systems, Alltech Dairy Solutions Symposium, University College, Belfield, Dublin 4, Ireland.

10. Whelan, S. J., F. J. Mulligan, V. P. Gath, B. Flynn, J. Callan, and K. M. Pierce. 2012. Dietary manipulation of crude protein and starch content affects energy balance in early lactation dairy cows. J. Dairy Sci. 95(Suppl. 2):198
11. Whelan, S. J., F. J. Mulligan, B, Flynn, J. J. Callan, and K. M. Pierce. 2012. Dietary protein as a regulator of energy metabolism in early lactation. Page 33 in Nutritional Management in Early Lactation- 2012 International Dairy Nutrition Symposium, Wageningen, The Netherlands

Task 8

1. Selbie D. Cameron, K.C., Di, H.J., Moir, J.L., Lanigan, G., Laughlin R.J., Richards, K.G. (2012) The fate of urine nitrogen with use of a nitrification inhibitor. In: Richards, K.G., Fenton, O., Watson, C. J. (Eds). Proceedings of the 17th Nitrogen Workshop – Innovations for sustainable use of nitrogen resources. 26th – 29th June 2012, Wexford, Ireland, pp. 19-20.
2. Richards K., Ernfors M., Cahalan E., Selbie D., Lanigan G. & Hennessey D. (2011) Reducing Nitrogen losses using nitrification inhibitors, In Buckley F. (Ed) Irish Dairying – Planning for 2015, Teagasc, Moorepark Open Day 29-06-2011 p 129-130.
3. Selbie, D., Lanigan, Gary, Di, H.J., Moir, J.L., Cameron, K.C. and Richards, K. (2011). Improving nitrogen efficiency using a nitrification inhibitor on urine-affected soil - a grassland lysimeter study. In: Ag. Research Forum, Tullamore, Co. Offaly, 14-Mar-2011, pg 2.
4. Selbie, D., Lanigan, Gary, Di, H.J., Moir, J.L., Cameron, K.C., Khalil, M. I. and Richards, K. (2010). Manipulating N excretion and the effect on N2O emissions from grassland soil. Proc. A Climate for Change Conf. Dublin 24-25 June. (Abstract) Conference Book of Abstracts p97
5. Selbie, D., Lanigan, Gary, Di, H., Moir, J., Cameron, K. and Richards, K. (2010). Importance of urinary N content on nitrous oxide emissions from grassland soil lysimeters. In: Ecotrons & Lysimeters Conf, Nancy, France, 29-Mar-2010, p15

(h) National Report – N/A

(i) Popular non-scientific publications

- Pierce, K, S. Whelan and F. Mulligan, Irish Farmers Journal. 2010
- Richards, K., Selbie, D., Cahalan, E., Dennis, S., Ernfors, M., Minet, E., Lanigan, Gary, Lalor, S., Murphy, J.B., Watson, C., Laughlin, R., McGeough, K., Mueller, C., Rooney, D., Cameron, K., Di, H., Khalil, I. and Hennessy, D. (2011). Reducing N loss using inhibitors. Tresearch 6 (2) p. 12-13.
- Selbie, D., Lanigan, Gary, Di, H., Cameron, K., Moir, J., Pierce, K. and Richards, K. (2009). Dietary manipulation to reduce environmental nitrogen losses. In: Ireland's Rural Env. Research highlights from Johnstown Castle. Teagasc IE p39

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

Tasks 4, 4a and 5

1. Data were presented at many Industry Training days which were held at UCD Lyons Research Days. At such events, representatives from the animal feed industry are offered advice on the implementation of low CP feeding strategies for the lactating dairy cow. Data where relevant also presented at the Teagasc Ruminant Nutrition (Fetac Level 6) course in 2010, 2011, 2012.

Task 8

1. Richards K., Ernfors M., Cahalan E., Selbie D., Lanigan G. & Hennessey D. (2011) Reducing Nitrogen losses using nitrification inhibitors, In Buckley F. (Ed) Irish Dairying – Planning for 2015, Teagasc, Moorepark Open Day 29-06-2011 p 129-130

7. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (months)	Average time contribution per permanent staff member
UCD	7	39	5.6
Teagasc Johnstown Castle	8	42.156	5.7
Total			

8. Researchers Funded by RSF

Type of Researcher	Number	Total Time contribution (months)	Average time
Post Doctorates	0		
Contract Researchers	0		
PhD postgraduates	3	91.56	30.52
Masters postgraduates	3	56.916	18.97
Temporary researcher	1	0.12	0.12
Other			
Total			

9. Postgraduate Research

Total Number of PhD theses: 3

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

- Grainne Meade: "The agronomic and environment implications of pig manure applications to Irish grown cereal crops". University College Dublin. Thesis submitted in July 2010.
- Stephen Whelan: "Dietary Manipulation of Nitrogen Balance in Lactating Dairy Cows" University College Dublin. Submitted in June 2012.
- Diana Selbie: "The effect of varying nitrogen loading rate on the fate of urine in a grazed pasture in Ireland". Lincoln University. Thesis is due to be submitted in March 2013.

Total Number of Masters theses: 3

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

- Diarmuid Murphy: "The effect of dietary manipulation of pig slurry on grass growth and ammonia and nitrous oxide emissions following land application". University College Dublin. Submitted in January 2010.
- Felicity Wurlod: "An examination of the effect of dietary essential oils on rumen fermentation using *in vitro* simulation techniques". University College Dublin. Submitted in July 2010
- Andrew McInerney: Not yet submitted. It is hoped that this student will return to his thesis for submission at some point during 2013.

10. Project Expenditure

Total expenditure of the project: € 640,679.77

Total Award by RSF € 651,661.91

Other sources of funding (specify) €
1.
2.

Breakdown of Total Expenditure

Category	Name Institution 1	Name Institution 2	Name Institution 3	Name Institution 4	Total
Contract staff					
Temporary staff	UCD				546.66
Post doctorates					
Post graduates	UCD	Johnstown Castle			244,654.41
Consumables	UCD	Johnstown Castle			208,578.66
Travel and subsistence	UCD	Johnstown Castle	Kildalton		21,814.62
Sub total					475,594.35
Durable equipment	UCD				17,975.54
Other	UCD				3,408.92
Overheads	UCD	Johnstown Castle			143,700.96
Total					**640,679.77**

11. Future Strategies

Outline development plans for the results of the research.

The area of reducing nitrogen excretion from food producing animals is one that remains of significant interest to scientists involved in animal nutrition and also to the animal feed industry. Funding has been received from DAFM in a recent Stimulus call to research and update nutritional values for commonly used feedstuffs in Ireland. Using diet formulation to reduce crude protein content and thus reduce excretion is a focus of this new study and it was informed by the results of 07536.

Further research funds from the New Zealand government under the global research alliance are possible. An expression of interest for this funding was recently shortlisted and a full proposal has been submitted. This research seeks to investigate the microbial processes contributing to di-nitrogen and N20 emissions. This is a collaborative proposal between AgResearch in New Zealand, Teagasc and the University of Brisbane.

12. Industry Collaboration

Summarise details of industry collaboration in the research project.

Metasmart used in Tasks 4 and 5 and formulation of the diets involved a company called Adisseo.