An Roinn Talmhaíochta, Bia agus Mara
Department of Agriculture, Food and the Marine

Research Stimulus Fund

Final Report

Measurement and abatement of ammonia emissions from agriculture (LOWAMMO)

DAFM Project Reference No: 13-S-430

Start date: 01/12/2013

End Date: 31/07/2018

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Collaborating Research Institutions and Researchers: Dr Rachael Carolan & Dr. John McIlroy (AFBI), Dr. Karl Richards, Dr Dominika Krol and Dr Paul Crosson (Teagasc) Dr. Karina Pierce, Dr. Tommy Boland (UCD)

Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental → Applied → Pre Commercial

1	2	3	4 X	5	6	7

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	**Priority Area I - Sustainable Food Production and Processing**

Key words: *(max 4)*
Agronomy, Nitrogen, Ammonia, Housing

1. Rationale for Undertaking the Research

This section should outline the rationale for carrying out the research and identify the need / problem to be addressed

The Gothenburg Protocol (UNECE, 1999) and the National Emissions Ceiling Directive (NECD) (2001/81/EC) (Anon, 2001) committed Ireland to reduce emissions of transboundary gases including ammonia (NH3), oxides of nitrogen NOx), sulphur dioxide (SO2) and volatile organic compounds. This legislation is aimed towards reducing emissions of those pollutants that cause acidification,

eutrophication and ground-level ozone in order to protect the environment and human health. Its long-term objective is to ensure that pollutant levels remain below their critical loads (i.e. the amounts of pollutants below which, significant adverse effects do not occur).
Under the NECD, national NH3 emissions were limited to 116,000 tonnes by 2020, and 1% below this ceiling from 2020 to 2030. Ireland has been in contravention of the NEC Directive since 2016, with emissions in 2018 (EPA 2020).

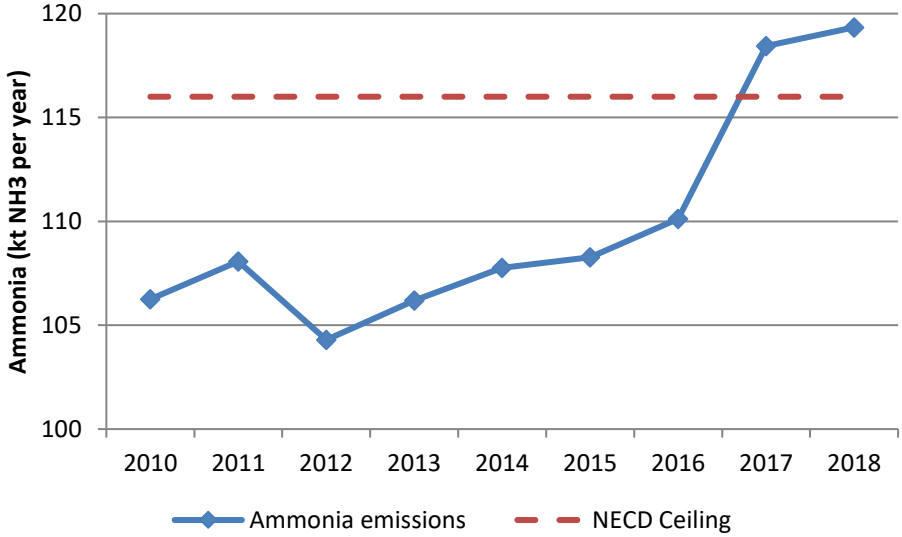

Figure 1: National ammonia emissions from 2010-2018. Data from EPA.

In Ireland, agriculture accounts for 99% of national NH3 emissions, with approximately 72% of emissions arising from cattle farming (EPA, 2013). Of the various farm activities, housing and storage of manures is the largest source of agricultural emissions and contributes 40% of national ammonia emissions. Emissions are projected to increase in the absence of mitigation due to a large increase in the number of dairy cows combined with an associated increase in chemical fertiliser use (Donnellan et al. 2018).

2. Research Approach

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

The project utilised a twin measurement and modelling approach to address ammonia emissions across different components of the manure management chain. The project was split into three distinct parts:
1) Direct measurements of ammonia were made in order to address the following research questions

A) What is the extent of ammonia emissions associated with urine and dung deposition on pasture? (Task 5)
B) What are the ammonia emissions associated with cattle housing, yards and storage of manures? (Task 3,4)
C) How much can ammonia emissions from housing and storage be reduced using Best Available Techniques (BAT) for abatement? (Task 7)

2) Direct measurements of nitrogen excretion in dung and urine were made following the imposition of low crude protein diets and associated dietary strategies in order to assess their potential impact on N losses (Task 6).

3) Modelling of ammonia emissions and mitigation options were subsequently undertaken in order to assess the impact of abatement at both a farm and national scale (Task2, 8).

1. *Ammonia emissions associated with dung and urine N deposition.* Ammonia emissions from dung and urine deposition were carried out across three seasons, at the Teagasc Johnstown Castle in Wexford using a system of wind tunnels (Meisinger *et al.*, 2001, Figure 2). Ammonia emissions associated with dung and urine N deposition. Ammonia emissions from dung and urine deposition on pasture and yards were carried out across three seasons, at the Teagasc Johnstown Castle in Wexford using a system of wind tunnels (Meisinger et al., 2001, Figure 2).
   Ammonia emissions from yards: Three experiments were established in order to assess a) ammonia emissions from yards and b) the abatement potential of washing and scraping.
   Experiment 1 consisted of 1 kg dung spread on the yards folled by 0.67l, 1l or 2l urine. Experiment 2 consisted of dung+urine with pressure washing after 1 hour, 3 hours and an unwashed control, while experiment 3 consisted of scraping after 1 hour, 3 hours or un-scraped (control).
   Ammonia emissions from dung/urine deposition onto pastures: The impact of dung and urine deposition during spring, summer and autumn were investigated using wind-tunnels. Also investigated was the impact of DCD (a nitrification inhibitor) addition to urine. A second experiment was established in order to assess the impact of adding urea fertiliser directly onto a urine patch, as well the addition of both nitrification inhibitors (DCD) and a urease inhibitor (NBPT).
2. *Ammonia emissions from naturally ventilated housing systems and yards:* Ammonia emissions were measured from four livestock farms (building "A", "B","C"&"D") in the south of Ireland over three winter housing periods (Nov to March). Emissions were measured using passive flux samplers (Ferm tubes, see Figure 3) for 24- hour periods on 4 to 7 occasions on each per building. The four buildings varied in floor type, size and the type and quantity of livestock housed. Emissions factors were calculated by dividing daily fluxes by the number of livestock units in the building. Figure 3.
3. The Potential of Chemical Amendments to Abate Ammonia Emissions. Four sets of different experiments were established to investigate: a) the impact of chemical amendments on hard standings, b) the impact of chemical amendments on stored slurry, c) the effect of adding waste streams from the agri-food processing sector on ammonia from stored slurry and d) the downstream impact of these amendments on ammonia emissions during landspreading. Ammonia emissions were measured using incubated containers connected via a manifold system to a photoacoustic analyser (Innova 1314, Lumasense, Denmark). This allowed for a large number of candidate amendments to be analysed (see Table 1). Subsequently, addition of the top three amendments was scaled up at the pilot facility built to assess ammonia abatement techniques at an intermediate scale (each tank contained 1 m^3 of slurry, Figure 4) while still allowing for replication. This slurry was subsequently landspread on grassland and ammonia emissions measured using wind-tunnels.
4. Bovine nitrogen excretion: The effect of different rumen-degradable carbohydrates on rumen fermentation and nitrogen metabolism of beef heifers offered grass silage was investigated in order to assess strategies that reduced nitrogen excretion and, subsequently ammonia emissions. The experiments were set up as a 3x3 Latin square design with six ruminally cannulated Belgian Blue cross heifers (487 ±29Kg BW).
   Experiment 1 Dietary treatments were grass silage + rolled barley, grass silage + maize, grass silage + soya hulls. All treatments were iso-nitrogenous (14% crude protein). Ruminal fluid was taken at various times up to 12 hours post-feeding.
   Experiment 2: Dietary treatments were grass silage:concentrates 50:50 and consisted 4 dietary of treatments: Low Protein (12%CP +/- chitosan) and High Protein (16%CP +/- chitosan). The rate of Chitosan inclusion was 10g kg DMI^{-1}.
5. Modelling and Cost Benefit analysis: Ammonia emissions were modelled at a national scale using an ammonia inventory model. The marginal abatement cost associated with individual measures was subsequently estimated and a marginal abatement cost curve (MACC) analysis was conducted.

3. Research Achievements/Results

Outline main results achieved

Ammonia emissions from housing systems and storage

The Ammonia emission factor associated with housing systems was quantified to be 13% of Total Ammonical Nitrogen (TAN). Emissions varied across farms and were related mainly N excretion, house temperature and windspeed (ventilation rate). Emissions per livestock unit (LU) ranged from 1.3 to 54 gNH3 LU-1 d-1 with a mean of 14.76 gNH3 LU-1 d-1. This agreed with a previous study in Ireland which estimated ammonia emissions to be 13.5 gNH3 LU-1 d-1. These values represent a reduction on the ammonia emissions cited in the Irish national ammonia inventory which utilises the UK value of 23.1 gNH3 LU-1 d-1 (Table 1). Emissions from storage tanks ranged from 1.05 to 1.67 gNH3 LU-1 d-1, which was similar to those observed by Misselbrook et al. 2015 for crusted tanks but only 50% the value of emissions associated with non-crusted tanks (Table 1).

Table 1: Ammonia emissions from housing in this study and three other studies.

Measurement technique	House type	NH_3-N lu^{-1} d^{-1}	Country	Reference
Ferm tubes	Slatted	14.76 (1.3 to 54)	Ireland	Current study
Ferm tubes	Cubicles with alleyways	44	Portugal	Pereira et al., 2010
Various	Cubicles with alleyways/slats	34.3	UK	Misselbrook et al., 2015
Various	Straw bedded	23.1	UK	Misselbrook et al., 2015

Store type	NH_3-N g m^2 d^{-1}	Country	Reference
Belowground tank (crusted)	**1.36 (1.05 - 1.67)**	**Ireland**	**Present study**
Aboveground open tank (crusted)	1.71	UK	Misselbrook et al., 2015
Aboveground open tank (non-crusted)	3.42	UK	Misselbrook et al., 2015
Aboveground open tank (crusted)	1.17	Italy	Balsari et al., 2007

Ammonia emissions from yards

Cumulative NH3 emissions increased linearly with increasing urine N rate and emission factors ranged from 46% to 67% of urine urea-N applied and from 22% to 29% of total N applied (Figure 3a). In experiment 2 and 3 the greatest reduction in cumulative NH3 emissions was obtained from pressure washing at 1h which reduced emissions compared to the non-cleaned control by 91% (Figure 3b & c).

Pressure washing at 3h reduced emissions by 80% while scraping after 1h and 3h reduced emissions by 78% and 54%, respectively. Farmers should be encouraged to clean their animal handling yards as soon as possible after use in order to maximise reductions in NH3 emissions from this source.

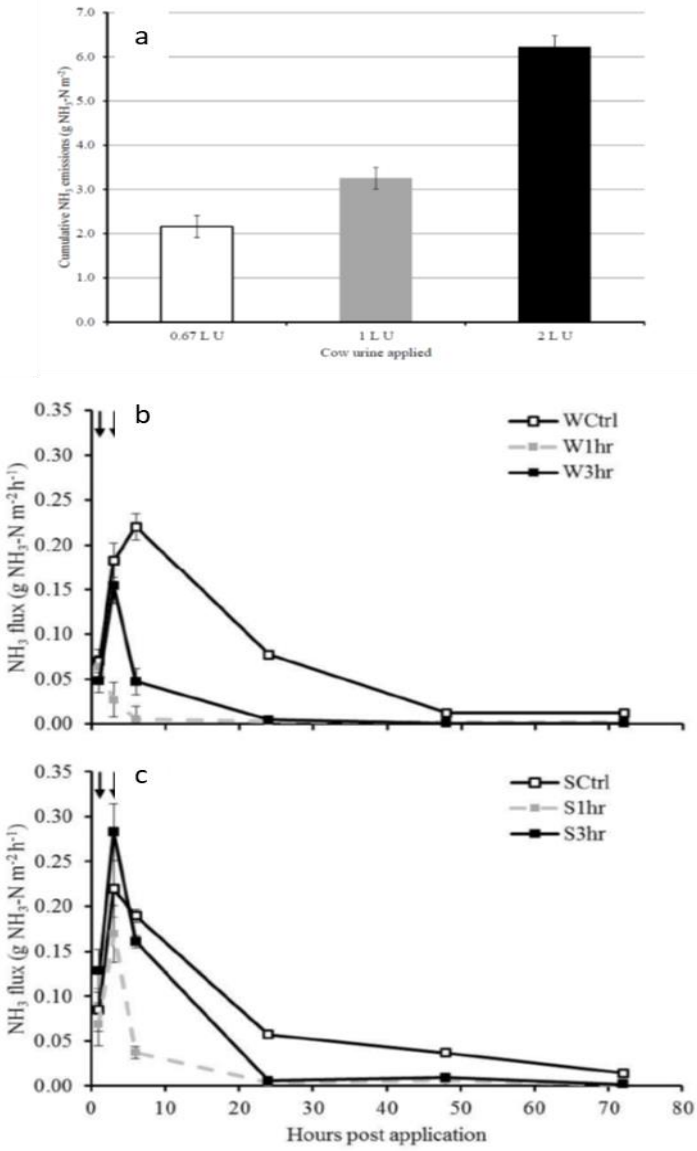

Figure 2: a) The impact of differing rates of urine application onto dung applied to a concrete yard, b) the impact of pressure washing and c) scraping 1 and 3 hours post-application.

Ammonia emissions during grazing

The ammonia emission factor associated with dung and urine deposition was estimated at 3.6% and 11.6% of N applied respectively, with the highest emissions during spring. This is most likely due to the fact that soil moisture was highest in spring and so would a) promote urea hydrolysis and b) slow the infiltration of urine and dung into the soil. The addition of DCD (for mitigating N2O emissions) had no

significant impact on ammonia loss.

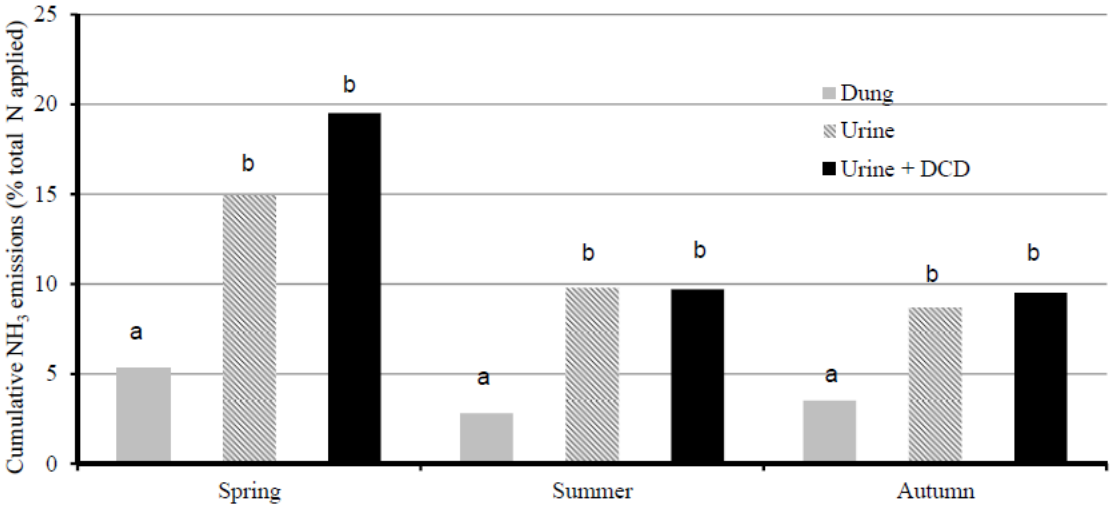

Figure 3: The impact on ammonia emissions of timing of dung and urine deposition onto pasture. Urine amended with DCD was also applied.

There was no significant reduction or increase in the ammonia emission factors from treatments receiving the two N stabilisers (NBPT and DCD) in the May and June application timings compared to the other treatments. The results of this study suggest that common farm practice of applying N fertiliser the day after grazing in rotational grazing systems offers no reduction in NH3 emission rates from urine patches where the N stabiliser inclusion rate is designed to reduce the fertiliser-based N losses only.

Impact of low crude protein on nitrogen excretion

The effect of carbohydrate sources of differing degradability on rumen nitrogen metabolism of beef heifers offered grass silage was evaluated. Cows were fed grass silage + rolled barley, silage + maize meal or silage + soya hulls. t. Rumen ammonia levels were initially elevated in the maize meal treatment but subsequently reduced compared to the other treatments. Offering grass silage supplemented with maize meal increased % N retained (N.S) and reduced % N excreted in urine and increased % N excreted in faeces.

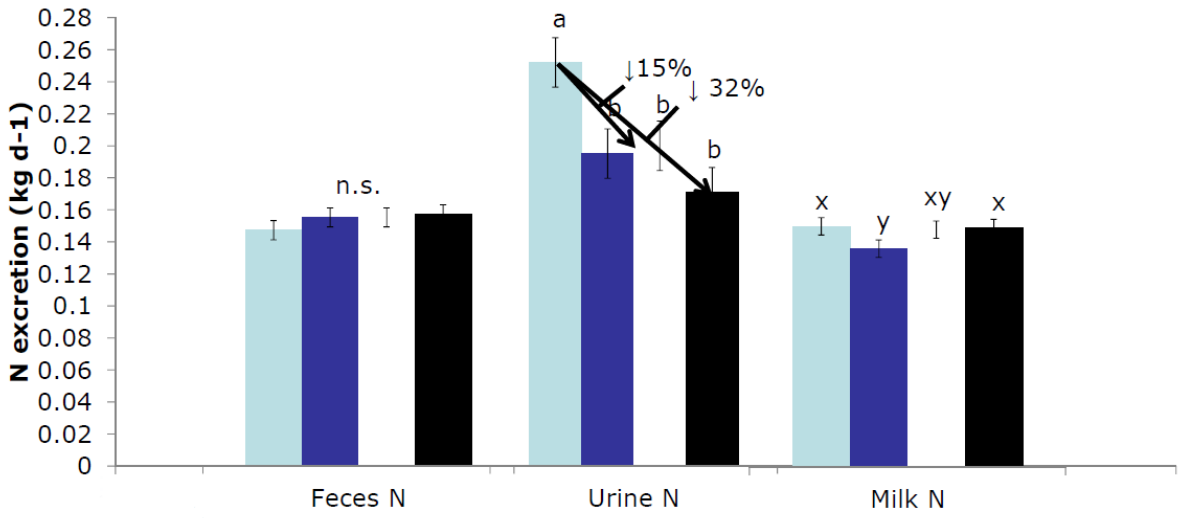

Figure 4: The impact of diet on N excretion and milk N levels. Treatments were High Protein, low Protein, low protein + barley, low protein+ maize

The high and low crude protein +/- chitosan experiment showed that crude protein has the biggest impact on nitrogen excretion (Figure 4). Chitosan had no significant impact on urine N excretions. In summary Carbohydrate source had little effect on total nitrogen excretion but potential to alter excretion pathways in finishing period. Reducing crude protein from 16% to 12% reduced urine N excretion by 10%.

The Impact of chemical amendments on ammonia and methane emissions.
In terms of chemical amendments ferric chloride, sulphuric acid, alum and acetic acid were extremely effective at abating emissions, with ammonia reduced by 96%, 85%, 82% and 73%, respectively. In terms of methane (CH4), ferric chloride, alum, sulphuric acid and acetic acid reduced emissions by 98%, 96%, 95% and 94%, respectively.

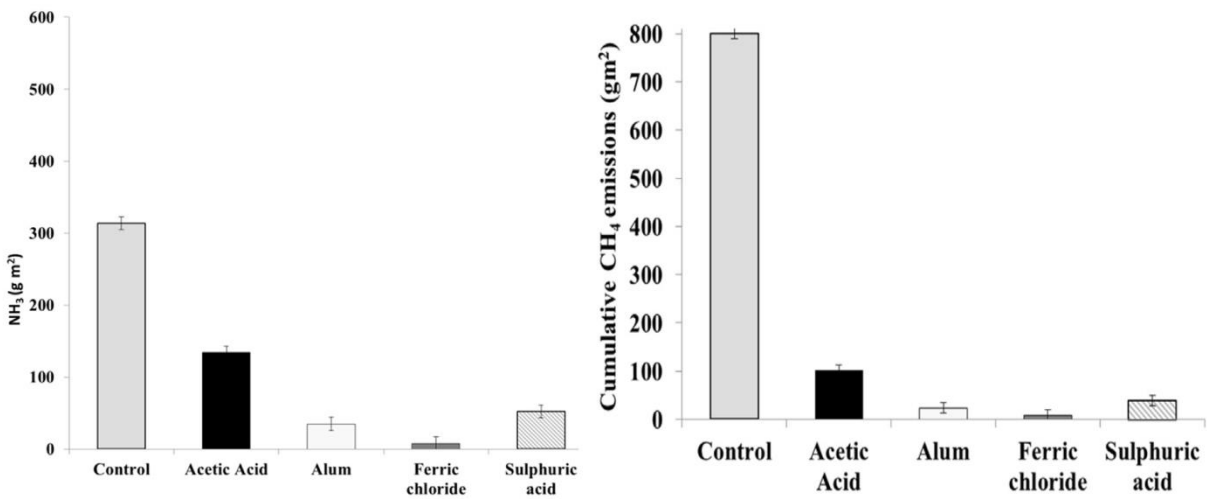

Figure 5: The impact of chemical amendments on ammonia and methane emissions during a 90-day storage period.

Ammonia abatement potential was observed for 5% sugar beet molasses (67% reduction), 7% apple pulp (49% reduction), and 7% grass silage (38% reduction). Commercially available additives had little impact on emissions, with the exception of one treatment Actisan from Agro Grassland, which reduced ammonia by approximately 10%.

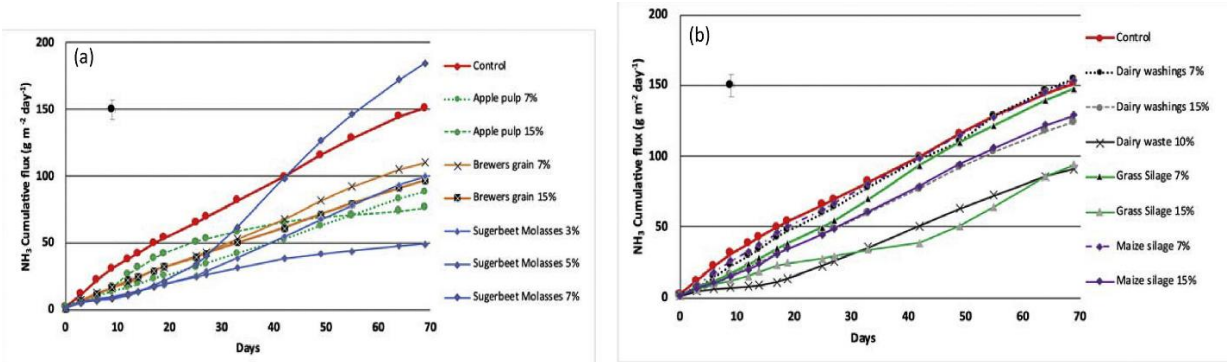

Figure 6: The impact of waste products from the food and drinks industry and silage effluent products on ammonia and methane emissions during a 90-day storage period.

Ammonia MACC

Using the FAPRI mdoel, agricultural activity was projected to 2030, These projections indicate that dairy cow numbers will increase to just over 1.6 million cows, whilst suckller cow numbers would decrease to circa 0.8 million cows. This would result in ammonia emisisons of

Compared to a Business as usual scenario, the average technical abatement potential was estimated to be approximately 15.26 kt NH3 at a net cost of €10.86 million per annum. However, it should be noted that the net cost (€10.86 million) is comprised of 6 measures that are cost negative (-€22.21 million) and 7 measures that are cost positive (€33.07) and that some of the cost negative measures are predicated on efficiency gains driven by best management practice adoption (e.g. liming and clover measures with associate chemical N reductions).

Amongst the thirteen mitigation measures selected for this analysis, 80% of the mitigation potential can be achieved by the full implementation of the mitigation pathways for protected urea and low emission slurry spreading (LESS) techniques for bovines.

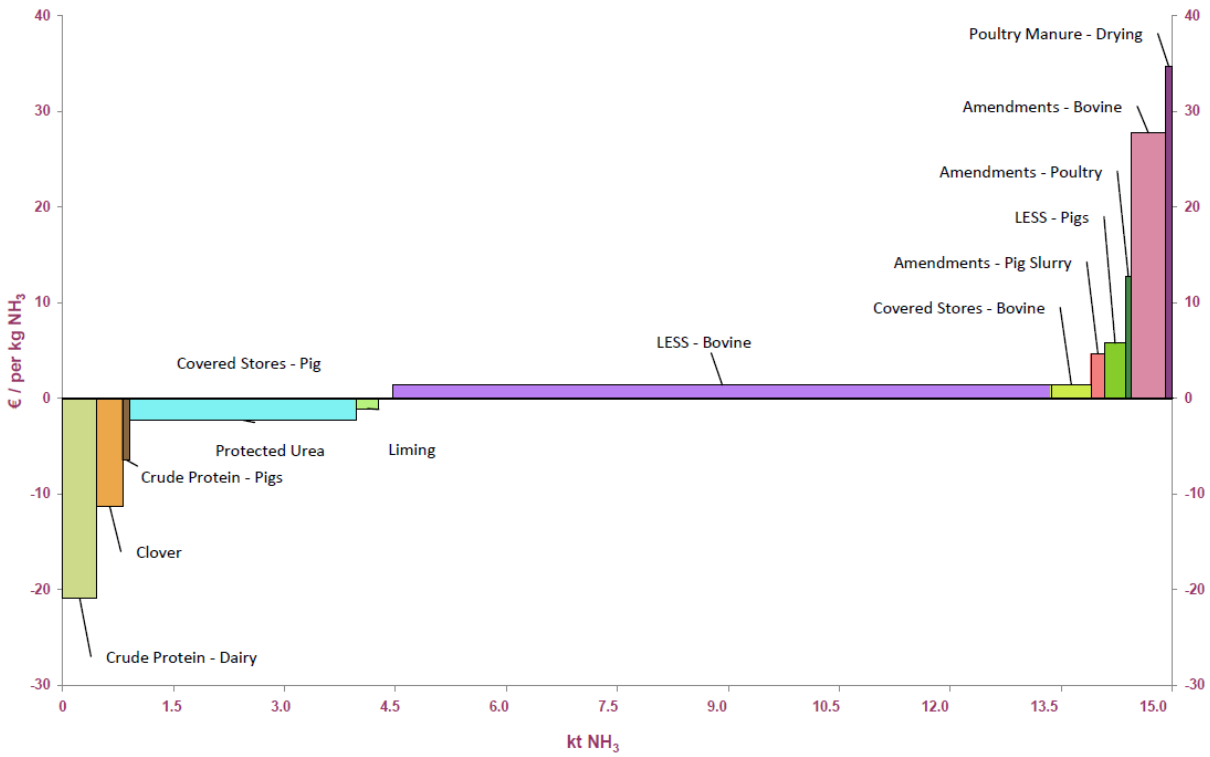

Figure 7: Marginal abatement cost curve indicating the main measures and cost per kilogram of ammonia abated.

4. Impact of the Research

A summary of the tangible impact of the research project should be provided under the outcomes' and 'outputs' heading below. In addition, please provide a short narrative synopsis of the benefits / improvements the research has made to the area under investigation particularly as regards end users, e.g. industry, consumers, regulatory authorities, policymakers, the scientific community, etc

- New emission factors for grazing and yard emissions have been incorporated into the national ammonia inventories. Housing/storage emission factors should be incorporated by 2022/23.
- Proven that chemical amendments that can reduce ammonia and methane from storage and hard standings
- Findings were incorporated into the Teagasc GHG MACC (chemical amendments) and the full range of measures were modelled and collated into the ammonia MACC. The ammonia MACC has subsequently helped to inform AgClimatise targets.
- The Project also majorly contributed to the RAMIRAN

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

The research team deepened research collaborative linkages between the partners and also with ADAS and Rothamsted Research in the U.K. The research team have developed links with several companies amendments, including Agro-Grassland and Devenish.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

Ammonia emissions via direct or indirect acidification has been confirmed as extremely effective for ammonia and manure methane abatement. The results of the project are being adopted as Tier 2 ammonia emissions factors for Ireland by the EPA in the national CLRTAP reporting.

(iii) Outcomes with economic potential

Several chemical amendments and waste-streams have been identified that could be exploited as ammonia and/or methane abatement strategies, including ferric chloride, alum, silage effluent and waste product from the cider industry. Only one commercially available produce, from Agro-Grassland was observed to significantly reduce ammonia emissions (from hard standings). This highlights the need for independent assessment of commercial products claiming ammonia abatement potential.

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

This project has important national implications. Most important has been the inputs into the GHG MACC and also the development of the Ammonia MACC.

4 (b) Summary of Research Outputs

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

1. Burchill, W., Lanigan, G.J., Forrestal, P.J., Misselbrook, T., Richards, K. (2017) Ammonia volatilisation from cattle urine patches, urea and the combination of urine patches with urea and stabilised urea in temperate grassland. *Nutrient Cycling in Agroecosystems* 108 (2), 163-175
2. Fischer, K., Burchill, W., Lanigan, G.J., Kaupenjohann, M., Chambers, B., Richards, K.G. and Forrestal, P.J. 2016. Ammonia emissions from cattle dung, urine and urine with dicyandiamide. *Soil Use and Management*. 32: 83-91. doi: 10.1111/sum.12203
3. McIlroy, J.P.; McGeough, K.L.; Laughlin, R.J.; Carolan, R. Abatement of ammonia emissions from dairy cow house concrete floor surfaces through additive application. Biosystems Engineering. 2019, 188, 320–330.
4. Kirwan, S.F.; Pierce, K.M.; Serra, E.; McDonald, M.; Rajauria, G.; Boland, T.M. Effect of Chitosan Inclusion and Dietary Crude Protein Level on Nutrient Intake and Digestibility, Ruminal Fermentation, and N Excretion in Beef Heifers Offered a Grass Silage Based Diet. *Animals* **2021**, *11*, 771
5. Kavanagh, I., Fenton, O., Healy, M.G., Burchill, W., Lanigan, G.J., Krol, D.J. (2021) Mitigating ammonia and greenhouse gas emissions from stored cattle slurry using agricultural waste, commercially available products and a chemical acidifier. *Journal of Cleaner Production* 294, 126251
6. Kavanagh I, Burchill W, Healy MG, Fenton O, Krol DJ, Lanigan GJ (2019) Mitigation of ammonia and greenhouse gas emissions from stored cattle slurry using acidifiers and chemical amendments. *Journal of Cleaner Production* 237:117822
7. Burchill, W., Reville, F., Misselbrook, T. H., O'Connell, C., & Lanigan, G. J. 2019 Ammonia emissions and mitigation from a concrete yard used by cattle. Biosystems Engineering, 184, 181–189.
8. Misselbrook, T., Wagner-Riddle, C., Richards, K. Lanigan, G.J., Burchill, W. and Salazar F. 2019 Sustainable Utilisation of Manures and Residue Resources in Agriculture. *Front. Sustain. Food Syst.*, https://doi.org/10.3389/fsufs.2019.00080
9. W Burchill, P J Forrestal, I Kavanagh and G J Lanigan 2017. Ammonia emissions from pasture-based production systems: a collation of Irish research. International Fertiliser Society No. 815 ISBN:978-

0-85310-452-0

(ii) Popular non-scientific publications and abstracts including those presented at conferences

Contributed paper - international conference

2017

1. Burchill W., Richards K.G. and Lanigan G.J. (Eds). "Proceedings of the 17th RAMIRAN conference – Sustainable utilization of manures and residue resources in agriculture. 4th – 6th September 2017, Wexford, Ireland"
2. Lanigan. G.J. Optimising Manure Management in Ireland Keynote Seminar 17th RAMIRAN Conference Wexford 5th Sept. 2017
3. Kavanagh, I., Burchill, W., Lanigan G.J. The impact of chemical amendements on ammonia emissions. 17th RAMIRAN Conference Wexford 4th Sept. 2017
4. Carolan R., McIlroy J. Gross nitrogen transformations in 15N labelled cattle slurry under simulated winter storage conditions. 17th RAMIRAN Conference Wexford 5th Sept. 2017
5. McIlroy J. Measurement and abatement of ammonia emissions (NH3) from naturally ventilated dairy cow house concrete floor surfaces under simulated north-west European conditions. 17th RAMIRAN Conference Wexford 5th Sept. 2017
6. Kirwan S., Pierce K., Boland, T. Effect of supplementary carbohydrate source on nitrogen excretion in beef heifers. 17th RAMIRAN Conference Wexford 5th Sept. 2017
7. Burchill, W., Lanigan G.J. Ammonia emissions from naturally ventilated buildings in Ireland 17th RAMIRAN Conference Wexford 6th Sept. 2017
8. Kale, A., Burchill, W., Curran, T., Lanigan, G.J. A review of nitrogen flow models and their suitability for temperate pasture based livestock systems Poster presented at the RAMIRAN 2017 Wexford 6th Sept 2017
9. Reville, F., Burchill, W., Misselbrook, T., O'Connor, C., Lanigan, G.J. Measurement and abatement of ammonia emissions from an outdoor concrete farmyard unfer Irish environmental conditions Poster presented at the RAMIRAN 2017: Sustainable Utilisation of Manures and Residue Resources in Agriculture. Wexford, Ireland 6th Sept 2017

2016

1. Lanigan, G., Burchill, W., Forrestal, P.J., Minet, E., Bourdin, F., Meade, G., Brennan, R., Cahalane, E., Watson, C., Fenton, O., Curran, T., Richards, K. 2016. Reducing gaseous emissions from manure management in Ireland. *Greenhouse Gases in Animal Agriculture, Melbourne, Australia, 14-18 February*.
2. McIlroy, J., McGeough, K., Laughlin, R., Carolan, R. Mitigation of NH3 emissions from Cattle Housing Floors Poster presented at the Sustainable N Conference 2016: Innovative Solutions For Sustainable Management of Nitrogen. Aarhus, Denmark
3. Burchill, W., Fischer, K. Forrestal, P.J., Minet, E., Krol, D., Lanigan, G.J., Kaupenjohann, M. and Richards, K.G. Ammonia and indirect N2O emissions from cattle dung, urine and urine in combination with fertiliser N coated with/without N inhibitors on temperate grassland. Poster presented at the Greenhouse Gasses and Animal Agriculture conference 2016. Melbourne, Australia.
4. Burchill, W., Fischer, K. Forrestal, P.J., Minet, E., Krol, D., Lanigan, G.J., Kaupenjohann, M. and Richards, K.G. Ammonia emissions from yards. Greenhouse Gasses and Animal Agriculture conference 2016. Melbourne, Australia.

2015

1. Gary Lanigan DECC/EMEP MEETING Presentation 'Techniques for the measurement of manure management emissions and the use of stable isotopes and biogeochemistry measurement techniques' 08/01/15-10/01/15 University of East Anglia, Norwich, UK
2. Gary Lanigan HORIZON2020 AMMONIA/GHG WORKSHOP Presentation 'Reducing N farm gate N surplus' 09/02/15-11/02/15 Brussels.
3. Gary Lanigan IIEA MEETING AND UCD CLIMATE MEETING Presentation 'Advances in AFOLU transboundary and GHG mitigation' 04/03/15-05/03/15
4. Gary Lanigan DG CLIMA WORKSHOP Presentation 'Abatement measures for reducing ammonia emissions in Ireland' 16/04/15-18/04/15 Brussels
5. Gary Lanigan DECC GREENHOUSE/EMEP MEETING Presentation 'Use of micro-meteorlogical techniques and dispersion modelling to estimate ammonia emission' 21/05/15 London, UK
6. Gary Lanigan ANAEE MEETING Participated in workshop 07/10/15-08/10/15

Paper/summary in proceedings of national conference

2018

1. Lanigan Gary., Patrick Forrestal, David Wall, Dominika Krol, Owen Fenton and Karl RichardsReducing emissions and nitrogen losses from beef cattle systemsProceeding of Beef 2018: pages 186-189 https://www.teagasc.ie/media/website/publications/2018/Beef-2018.pdf

2016

1. Kale, A.P., Lanigan, G.J., Burchill, W., Curran, T. and Crosson, P. Modelling ammonia emissions from livestock systems in Ireland Poster presented at the ENVIRON 2016 conference, Limerick, Ireland
2. Burchill, W., Misselbrook, T., and Lanigan, G.J. Ammonia emissions from two naturally ventilated cattle buildings in Ireland. Paper presented at the LivestockWaste2016 conference: Pollution Control and Resource Recovery for the Livestock Sector, NUI Galway, Ireland.
3. Burchill, W., Fischer, K. Forrestal, P.J., Lanigan, G.J., Kaupenjohann, M. and Richards, K.G. Ammonia emissions from cattle dung, urine, urine in combination with dicyandiamide and urea fertiliser formulations with/without N stabilisers on temperate grassland. Poster presented at the LivestockWaste2016 conference: Pollution Control and Resource Recovery for the Livestock Sector, NUI Galway, Ireland.

2015

4. John McIlroy Presentation to visiting Chinese Delegation Mitigation of Ammonia Emissions from Agriculture: A UK and Irish Perspective 19/10/15
5. John McIlroy Presentation of Task 7 preliminary results to CAFRE Mitigation of Ammonia Emissions from Dairy Farming 25/11/16

(iii) National Report

6. Buckley, C., Krol, D., Lanigan, G.J., Donnellan, T., Spink, J., Hanrahan, K., Boland, A., Forrestal, P.J., McClutcheon, G., James Humphreys, Murphy, P., NiFhlatharta, N., O'Brien, D., O'Dwyer, T., O'Mara, F., Richards K.J. and Waters, S. 2015. An Analysis of the Cost of the Abatement of Ammonia Emissions in Irish Agriculture to 2030. Teagasc , Oak Park.
7. Lanigan, G.J., Donnellan, T., Hanrahan, K., Burchill, W., Forrestal, P., McCutcheon, G., Crosson, P., Murphy, P., Schulte, R., Richards, K., Browne, P. 2015 A Marginal Abatement Cost Curve fot Ammonia Emissions in Irish Agriculture. Teagasc. Oak Park, Carlow.

(iv) Workshops/seminars at which results were presented

1. LOW-AMMO organised the 2017 RAMIRAN Conference. The 17th international RAMIRAN conference took place from September 4-6, 2017. This is the first time that this world-leading biannual conference was held in Ireland.
2. Final Project Stakeholder meeting. "Ammonia emissions in Irish Agriculture", Teagasc Ashtown Friday May 10th 2019.

5. Scientists trained by Project

Total Number of PhD theses: 1

1. Kirwan S. 2018 UCD. The effect of feed strategies on nitrogen metabolism in beef cows.

Total Number of Masters theses: 2

1. Fischer, K. 2015. Technische Universität Berlin, Germany. M.Sc. thesis. Ammonia emissions from bovine dung and urine in temperate maritime grassland.
2. Kavanagh I 2018 NUI Galway MSc. Impact of chemical amendements and waste products on ammonia during storage and landspreading
3. Kale A 2018 MSc UCD Modelling of ammonia emissions in Irish Farms

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
Teagasc Johnstown Castle	4	3.24
AFBI	12	1.18
UCD	2	0.15
Teagasc Moorepark	1	0.04
Total	**19**	**4.61**

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	0	0
PhD students	2	3.75
Masters students	0	
Temporary field assistants	8	2.5
Research Technician	1	3
Total	**11**	**9.25**

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
Leanne Roche	Information for hot topics in agri-food research – professional skills for the early career agri-food researcher – September 2013
Mary Harty	Science Writing - Sept 2014
Mary Harty	Career Management Skills for the Agri-Food Researcher - Nov 2015
Dominika Krol	Information for Hot Topics in Agri Food Research - Professional skills for the early-career Agri-Food Researcher

9. Project Expenditure

Total expenditure of the project:	€1156155.14
Total Award by DAFM:	€1,249,939.67
Other sources of funding including benefit in kind and/or cash contribution(specify):	N/A

Category	Teagasc JC	Teagasc Moorepark	Teagasc Grange	UCD	AFBI	Total
Staff	223472.01	0	0	16403.81	96045.93	335921.75
Students	95333.3	0	0	73871.28	0	169204.58
Consumables	150567.01	0	0	43475.87	66971.27	261014.15
Travel and subsistence	45839.95	47.62	0	6576.06	3159.07	55622.7
SUB TOTAL	515212.27	47.62	0	140327	166176.3	821763.18
Durable equipment	34003.4	0	0	5203.02	0	39206.42
Other	1590	0	0	0	0	1590
Sub-Contracting Costs	47066.59	0	0	0	0	47066.59
Overheads	154563.681	14.286	0	42098.11	49852.88	246528.954
TOTAL	752435.941	61.906	0	187628.1	216029.2	1156155.14

10. Leveraging

Summarise any additional resources'/funding leveraged by this award from other sources e.g. Additional Staff, National/EU funding secured, EI Commercialisation Fund, etc.

Through this project we have leveraged further funds from the Devenish nutrition to support extension on Ian Kavanagh's MSc to a PhD. The project also led to the successful funding of a SFI project looking at acidification with nitric acid as a means to enhance manure N content and reduce ammonia and methane emissions.

11. Future Strategies

Outline development plans for the results of the research.

There are plans to investigate a number of other strategies that reduce ammonia emissions, including the use of injection and the introduction of acidification of slurry on the tanker itself as well as low-emission housing systems and the use of farm features, such as shelterbelts for the interception of ammonia.