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

Research Stimulus Fund

Final Report

'The Agricultural Greenhouse Gas Research Initiative for Ireland (AGRI-I)'

DAFM Project Reference No: 10 S 716

Start date: 15/12/2011

End Date: 30/09/17

Principal Coordinator and Institution: Gary Lanigan, Teagasc Johnstown Castle
Email: gary.lanigan@teagasc.ie

Collaborating Research Institutions and Researchers:
Teagasc, Johnstown Castle: Creamer, Rachel, Richards, Karl, Forrestal, Patrick, Krol, Dominika
Teagasc, Grange: O'Kiely, Padraig, Waters, Sinead, Kenny, David
Teagasc, Ashtown: Fealy, Reamonn
AFBI: Catherine Watson, Elzabeth-Anne Wasson, Ronnie Laughlin, Dario Fornara, Karen McGeough, Rachael Carolan
Trinity College Dublin: Mike Jones, Mike Williams
University College Dublin: Bruce Osborne, Evelyn Doyle, Christophe Mueller
University of Limerick: Ken Byrne, Achim Schmalenberger

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	3x	4	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)	This project directly addressed two key priority areas identified by the NRPE and DAFM's Stimulating Sustainable Agricultural Production through Research & Innovation (SSAPRI) Report: 'Measurement of impact of mitigation strategies including development of emissions factors lead to increased national greenhouse gas emissions, both impacting on our national commitments and increasing the C footprint of Irish agricultural produce' and 'Development of models /Metrics and advanced methodologies to verify environmental efficiency of Ireland's primary food production systems'.

Key words: *Greenhouse gas, mitigation, inventories, models*

1. Rationale for Undertaking the Research

Food Harvest 2020 and Food Wise 2025 envisaged ambitious expansion, both in terms of the volume and value of output, for the agriculture sector as a whole and particularly for the dairy sector (DAFM 2011). Whilst these targets both envisaged and later resulted in increased dairy production, this expansion has occurred within an EU policy context whereby greenhouse gas emissions (GHG) must be reduced. Under the EU Climate and Energy legislation and associated Effort-Sharing Directives, Ireland has been set a 30% reduction target by 2030 (EU 2010). As agriculture comprises over 40% of this category of emissions, there has been and continues to be sustained pressure into the future to reduce emissions.

Allied to this, consumer and retail awareness of climate-related issues within the sector is demanding that emissions intensities of agricultural produce, that is the amount of GHG's per unit product, is as low as possible. Indeed, the FoodWise itself stated that one of Irelands key marketing strategies is focussing on its 'green' low-input grass-based production systems (DAFM 2015). In addition, there is a growing realisation that improved emissions intensity is allied to increasing production efficiency, particularly in terms of farm nitrogen (N) flows. As a result, decreasing emissions intensity is allied to increased farm economic sustainability, particularly in the context of higher input costs.

Agricultural emissions have been in steady decline since 1998, with total sectoral emissions 9% lower than the 1990 reference levels (Duffy et al., 2011). Nevertheless, in 2010 agriculture accounted for 18.7 Mt CO2-eq, or 30.4% of national emissions, with only New Zealand having a higher proportion of total GHG emissions associated with agriculture (NZ-MoE, 2010). Methane (CH4) and nitrous oxide (N2O) make up the vast bulk of emissions due to of the dominance of cattle and sheep livestock production in Irish agricultural output. Methane emissions sourced from livestock enteric fermentation is the primary source of greenhouse gases, accounting for almost 50% of total emissions, whilst N2O emissions arising as a result of chemical/organic fertilizer application and animal deposition comprise a further 38% (Duffy et al. 2011).

Scenarios assessing the impact of Food Harvest 2020 implementation have predicted an increase in emissions, principally due to increases in dairy cow numbers and increased intensification, with emissions as high as 19.5 Mt CO2-eq by 2020 (Schulte et al. 2010). This value does not account for the impact of mitigation strategies or any contraction in emissions following a reduction in the size with proportionate and absolute terms, with this increase driven mainly by higher N2O emissions associated with increased synthetic fertiliser application (Duffy et al. 2011).

There are clear conflicts between the capacity to increase production and compliance with sustainability criteria, most notably, climate change targets. Future expansion will require the adoption of mitigation strategies.

2. Research Approach

This project employed a dual measurement and modelling approach in order to a) quantify carbon sequestration levels in Irish grasslands, b) refine N_2O emission factors in national inventories, c) assess the role of changing rumen microbial communities on methane emissions and d) model the impact of mitigation at a national scale.

Carbon sequestration – Measurement of C sequestration was performed using a) soil sampling and b) measurement of CO_2 fluxes. Soil organic carbon was further partitioned between labile C pools and stable/recalcitrant C pools in order to a) assess the permanence of the C sink and b) provide better calibration for the biogeochemical models. Partitioning was made on the basis of physical and chemical protection of carbon. Physical protection was assessed by wet sieveing and particle size analysis – this partitioned OC into macroaggregate-associated C, microaggregate-associated C and silt/clay associated C. The macro- and micro-aggregate C was further divided into intra-particulate OC and mineral-associated OC. Chemical recalcitrance was assessed by partitioning C into hot water extractable C (labile pool), acid resistant C (stable pool) and the remainder (an intermediate pool). Ecosystem CO2 and energy fluxes will be measured using the eddy-covariance (EC) flux technique. This is the standard technique for quantifying eco-system scale greenhouse gas fluxes and relies on the measurement of variations in vertical wind velocity and trace gas concentration above the source surface with high time resolution. The eddy covariance technique provides the most robust measure of not only net ecosystem production but also allows for the partitioning of Net Ecosystem Productivity into Gross Primary Production and Total Ecosystem Respiration (TER).
In order to assess the role of soil microbes (fungi and bacteria, microbial community structure was analyzed via bacterial 16S rRNA gene and fungal internal transcribed spacer region terminal restriction fragment length polymorphism. Bacterial and fungal abundance was determined via quantitative PCR aiming at the same genetic targets.

Nitrous oxide- This work package was structured around three tasks. Tasks 1 and 2 investigated the effect of fertiliser formulation and timing on N_2O emission factors for grazed grasslands and spring barley systems on a range of soil types, respectively. Task 3 dis-aggregated N_2O emission factors for the IPCC grazing class pasture, range and paddock across a range of soil types. As the work was spatially and institutionally dispersed, a common measurement and analysis protocol was essential. A common sampling methodology, chamber design and GC analysis protocol was developed in conjunction with the InveN2Ory Project. This resulted in directly inter-comparable datasets, not only between different Irish research groups but between UK and Irish N_2O datasets and means that results and generated emission factors can be readily extrapolated between groups.
Stable isotope (^{15}N) tracer studies were also undertaken in order to quantify the impact of various N forms on N_2 emissions. The ^{15}N enrichment of the NH_4^+ and urea-N pools had to be labelled at a high level (40-60 atom %) in order to distinguish N_2 emissions from the high natural N_2 backgound (80% of atmosphere is comprised of N_2).

Methane- The two JPI-FACCE funded projects (Global Networks and RumenStability) had a variety of approaches. GlobalNetworks was a synthesis/data-gathering project, whereby the impact of animal diet and feeds on methane emissions were collated together. Irish involvement was limited to providing grass quality data and some methane emissions. RumenStability was a project focussed on understanding the rumen microbiota and a) how it changes over time and b) how diet might impact it. In addition, it was tasked to identify specific methanogens. The approach taken utilised targeted amplicon sequencing and metabolite profiling to examine the effect of feed efficiency (FE), both nutritionally induced through management practices and measured as residual feed intake (RFI), on rumen archaeal and bacterial populations and rumen fermentation. The initial studysequenced mcrA cDNA amplicon libraries to assess the abundance and diversity of transcriptionally active methanogens present in the bovine rumen of animals undergoing dietary restriction and subsequent compensatory growth. The relationship between FE phenotype (measured as RFI) and rumen archaeal and bacterial populations and rumen fermentation parameters was subsequently explored.

Biogeochemical modelling-Various process models were examined in order to assess their efficacy in predicting N2O emissions and soil C changes. The models were calibrated using a) the soil C data collected in SIS and the C sequestration work package. In particular, the partitioning of C using physical and chemical methods was used in order to calibrate the initial partitioning of C between fast and slow turnover pools in the models.

Socio-economic analysis- In order to assess and rank measures in order of cost-effectiveness, a marginal abatement cost curve analysis was undertaken. This analysis utilised the full suite of data and modelling collated during the lifetime of the project as well as previous Teagasc -, DAFM, EU- and EPA- funded projects. A combination of inventory and process-based models was utilised, in conjunction with an economic analysis (FAPRI) in order to assess measures and predict the future agricultural activity data.

3. Research Achievements/Results

Co-ordination with internal and external Research Initiatives: Consortium Agreements were signed with UK GHG Platform and NZAGRC. Joint emission factors using combined UK/Ire data between the UK/Ireland for slurry N_2O are currently being submitted to EPA/DEFRA. A joint emissions factor database has been established between AGRI-I and the UK GHG Platform. Ireland and NZ co-operated on a number of MPI-funded projects including Feeding inhibitors to bovines, N_2O decision support systems and soil carbon management in pastures.

Carbon sequestration: Our studies on carbon sequestration have shown that when soil carbon is sampled down to 1 metre, 50% of SOC stocks are found in the top 30 cm (the IPCC depth to which SOC is measured) and 50% at lower depths. However, most of the very stable carbon is located at depths below 30 cm (42% of subsoil SOC is located in stable micro-aggregates and silt and clay, compared to 16% in the topsoil). This

particularly occurs in soils that are subject to clay illuviation and from analysis of the chemical characteristics of this carbon, it has moved into the subsoil due to high rainfall in these areas.

This finding has large implications as it has been previously thought that soil carbon stocks reached an equilibrium several decades after a land-use or land management change has occurred. We have found that this equilibrium may not occur to the extent that we thought. Different microbial communities were also observed to utilise different C sources, with distinct communities associated with silt/clay associated organic carbon (recalcitrant pool).

The impact of drainage of mineral soils on SOC was also assessed and the potential of re-wetting organic soils was also examined. Rewetting up to half of the area of histic soils that are currently artificially drained would amount to a 3.2 million tonnes CO_2 saving. Decreasing drainage depth and raising average water table to -25cm in 50% of all deep drained, nutrient rich grasslands is estimated to result in annual emission savings of 0.4 million tonnes CO_2 .

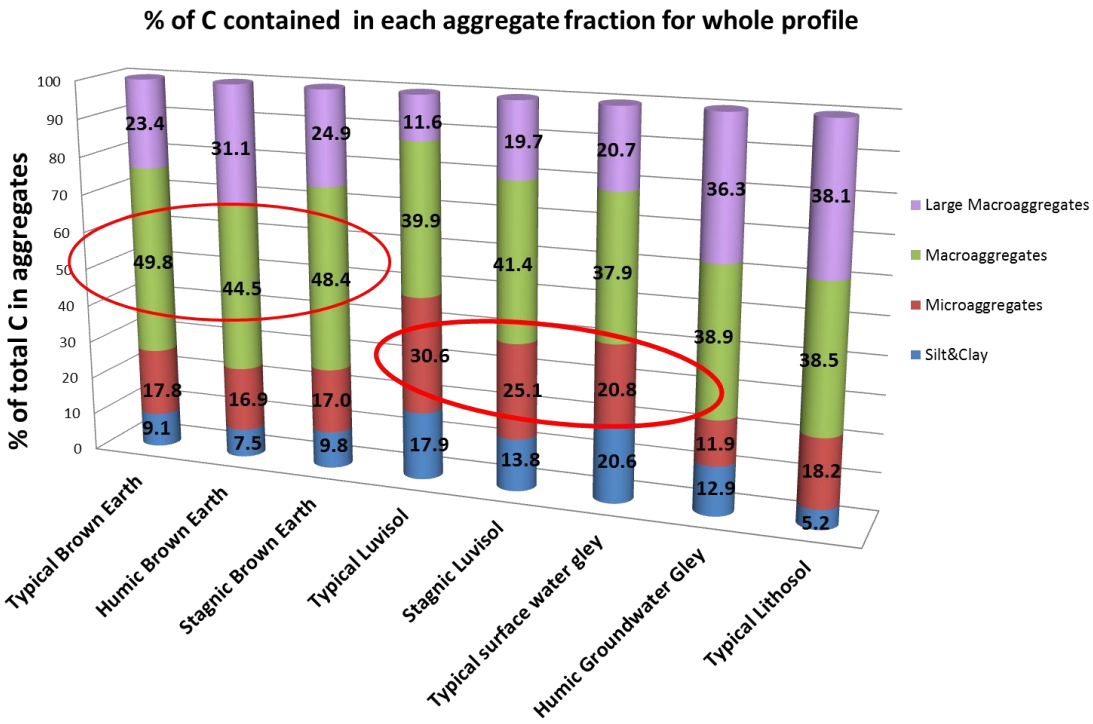

Figure 1: Proportion of soil orgaic carbon contained in each of the four C pools measured. Turnover time of C in each pool is as follows: Large macroaggregates - >2 years, macroaggregates - >10 years, microaggregates – 70 – 150 years, silt/clay OC – 250 – 800 years.

Nitrous oxide: Prior to this project, all organic and mineral nitrogen fertiliser was assumed to have an N2O emission factor of 1% (ie. 1% of applied N is converted to N_2O termed EF1) and the excreted N emission factor was 2%. This meant that N mitigation could only occur by reducing that amount of N applied, rather than the type of N.

Results from three years of field trials at Johnstown Castle, Moorepark and Hillsborough demonstrated that N_2O emissions from CAN were significantly higher than those from straight urea and urea combined with Nbtpt (a urease inhibitor), DCD (a nitrification inhibitor) or both inhibitors (see Figure 2). Soil type also had a significant effect, with emissions from heavier soils (Hillsborough) 3-4 times higher than those from fertiliser applied to lighter soils (Moorepark).

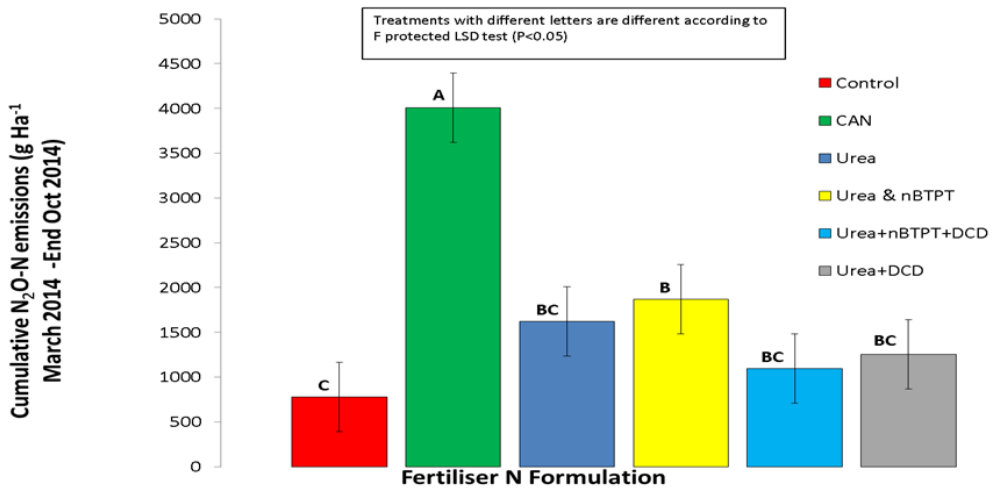

Figure 2: Mean cumulative N_2O emissions for CAN, straight urea, urea coated with Nbtpt, urea combined with DCD, urea containing both inhibitors and control (no fertiliser) treatments.

When averaged over the full three year period and across grassland sites, the EF1 for CAN rose to 1.49%, while EF1 for urea fertilisers were all below 0.4% (Table 1). The N_2O emission factor for CAN on arable soils was significantly lower than from grassland soils. This was due to the fact that nitrification rather than denitrification was the primary source of N_2O due to the cropland site being on a very free-draining, low % clay brown earth. This also agrees with previous research conducted on N_2O from croplands in Ireland, with the low N_2O considered to be principally a soil type effect. Similar trials were conducted for dung and urine at the three sites and EF3 was disaggregated between dung and urine. The emission factor (EF3) was observed to be 41% and 84.5% lower than the default value for urine and dung respectively. This has had a major impact on agricultural GHG inventories and lowered recorded GHG emissions by 750,000 tonnes CO_2e or 3.8% of agricultural emissions.

Table 1: Revised and disaggregated country-specific N2O emission factors for mineral fertilisers, dung and urine. The default EF for fertiliser was 1% and EF for dung urine was 2%.

Grassland	EF %
Urea	0.25
Urea+NBPT	0.4
Urea+NBPT+DCD	0.11
Dung	0.31
Urine	1.18
Arable	**EF %**
CAN	0.35
Urea	0.27
Urea+NBPT	0.2
Urea+NBPT+DCD	0.16

Methane:
The effect of diet on the rumen methanogen populations of Charolais and Holstein Friesian steers phenotypically divergent for residual feed intake were examined. For this study rumen fluid samples have been collected via stomach intubation during each dietary phase: high concentrate, ad libitum grass silage, zero-grazed grass, grazed grass and high concentrate. Samples were immediately snap frozen in liquid nitrogen and are currently stored at -80°C. With this study it is our objective to combine both a metabolomic investigation with a microbial characterization, diversity and functionality analysis to gain a greater understanding of the bovine rumen ecosystem in relation to dietary transition and feed efficiency.

The results showed that the quantity of feed consumed can evoke large effects on the composition and diversity of transcriptionally active methanogens (such as *Methanobrevibacter gottschalkii*) in the rumen of cattle. Microbial sequencing analysis of the rumen digesta has provided evidence that the abundance of certain bacterial genera such as Fibrobacter, exhibit relationships with RFI phenotype. It is hypothesized that this is due to their role in the ruminal degradation of complex plant polysaccharides or increased capability to harvest nutrients from ingested feed. Ruminant FE phenotype was observed to influence the rumen microbial ecosystem, though this effect appears to be dependent on diet type and host animal genetics when steers are growing. *Methanobrevibacter* Y315 showed a continuous negative relationship with RFI in the rumen fluid of cattle offered a concentrate diet irrespective of breed or age.

Modelling and socio-economics:
Modelling N and C Cycling: Model inter-comparisons were made in order a) assess which model was the most adaptable and suitable to Irish conditions and b) assess the

uncertainty range associated with biogeochemical models. We analysed the performance of the three mechanistic models, DailyDayCent (DayCent), DeNitrification-DeComposition (DNDC 9.4 and 9.5), and ECOSSE when simulating N2O and CO2 fluxes from two different land uses (simulated grazing and spring barley) under a range of fertiliser types and application rates. Model performance was assessed using linear regression analysis, root mean square error (RMSE), and relative error. Monte Carlo analysis was carried out to assess the sensitivity of DayCent and ECOSSE to changes in the timing of management events.

When averaged across all sites and treatments DayCent simulations produced the lowest number of significant total and relative errors. When looking at the relationship between modelled and measured N_2O fluxes, ECOSSE performed best with a significant relationship in 61.8% of all simulations and an average r2 of 0.2. However, outputs from this model displayed the largest total and relative errors. Performance when simulating cumulative fluxes was generally poor. The Monte Carlo analysis showed that shifts in timing of management events by ±7 days lead to annual N2O fluxes varying by 5.6 ± 7.6% and 2.8 ± 4.2% for grassland and cropland, respectively. Predictions of ecosystem respiration by both DailyDayCent and DNDC showed reasonable agreement with Eddy Covariance data (R2= 0.34-0.41, $p < 0.05$).

Marginal Abatement Cost Curve: In order to assess the potential impact of the full suite of measures available and rank them in terms of cost-benefit, a marginal abatement cost curve analysis was undertaken. Three steps were undertaken for this analysis:

1. Future business as usual GHG emissions were modelled using the FAPRI-Ireland model

The analysis was broken down between a) agricultural emissions, b) land-use, land use change, c) energy. This reflects Teagasc's four point approach to reducing GHG emissions:

- stabilise methane emissions through increased efficiencies.
- de-couple nitrous oxide emissions from production via nitrogen use efficiency and the use of low emission fertilisers and spreading techniques.
- absorb CO_2 via carbon sequestration in forests and soils while also reducing CO_2 emissions from hotspots (organic soils).
- fossil fuel displacement has the potential to offset fossil fuel emissions either by energy saving measures or substitution with bioenergy.

In the absence of any mitigation, agricultural GHG emissions are projected to increase by 9% by 2030 relative to the 2005 baseline. This projected increase is mainly driven by increased dairy cow numbers and fertiliser use. However, the extent of any increase by 2030 is highly uncertain and may increase or decrease dependant on changes in total animal numbers and fertiliser inputs.

Agricultural Mitigation: The total *mean abatement potential* arising from cost-beneficial, cost-neutral and cost-positive mitigation measures for *agricultural* emissions (methane and nitrous oxide) and assuming linear rates of uptake was 1.85 Mt of carbon dioxide equivalents (CO_2-e) per annum between 2021 and 2030, compared to the baseline scenario. The *maximum annual abatement* in the year 2030 was 3.07 Mt of carbon dioxide equivalents (CO_2-e, Figure 3a).

Land Use Mitigation: The enhancement of CO_2 removals could potentially remove another 2.97 Mt CO_2-e per annum on average from 2021-2030. The maximum annual removal in the year 2030 was 3.89 Mt of carbon dioxide equivalents (CO_2-e). However, under current flexibilities, sequestration would be capped at 2.68 Mt CO_2-e per annum (Figure 3b).
Fossil Fuel Displacement: The cultivation of biofuel/bioenergy crops along with adoption of anaerobic digestion and biomethane and on-farm energy saving has potential to account for a further reported reduction of 1.37 Mt of CO_2-e per annum from 2021-2030, mainly associated with the displacement of fossil fuel usage. The *maximum annual abatement* in the year 2030 was 2.03 Mt of carbon dioxide equivalents (CO_2-e). However, in the National Emissions Inventory, these reductions would largely be attributed to the fuel consuming sectors, i.e. the transport sector and power generation sector.
Costs: The costs of these measures over the period under consideration (2021-2030) are highly variable as they are sensitive to uptake rate and other associated externalities. The total level of abatement of all three categories averaged over the period 2021-2030 and assuming linear uptake of all measures was 6.19 Mt CO_2-e yr^{-1} per annum. By the year 2030, *maximum level of uptake* should be achieved. These will equate to total mitigation of 8.99 MtCO_2-e comprised 3.07 Mt CO_2-e for agriculture, with further mitigation of 3.89 Mt CO_2-e and 2.03 Mt CO_2-e from the land-use and energy sectors respectively. The optimal carbon price, at which most mitigation could be achieved was assessed to be €50 per tonne CO_2e and these measures are listed in Table A below. This results in a total cost-effective mean mitigation value of 5.53 Mt CO_2-e yr^{-1} between 2021-2030 and a maximum cost-effective abatement value of 7.795Mt CO_2-e in 2030 (Figure 3c).

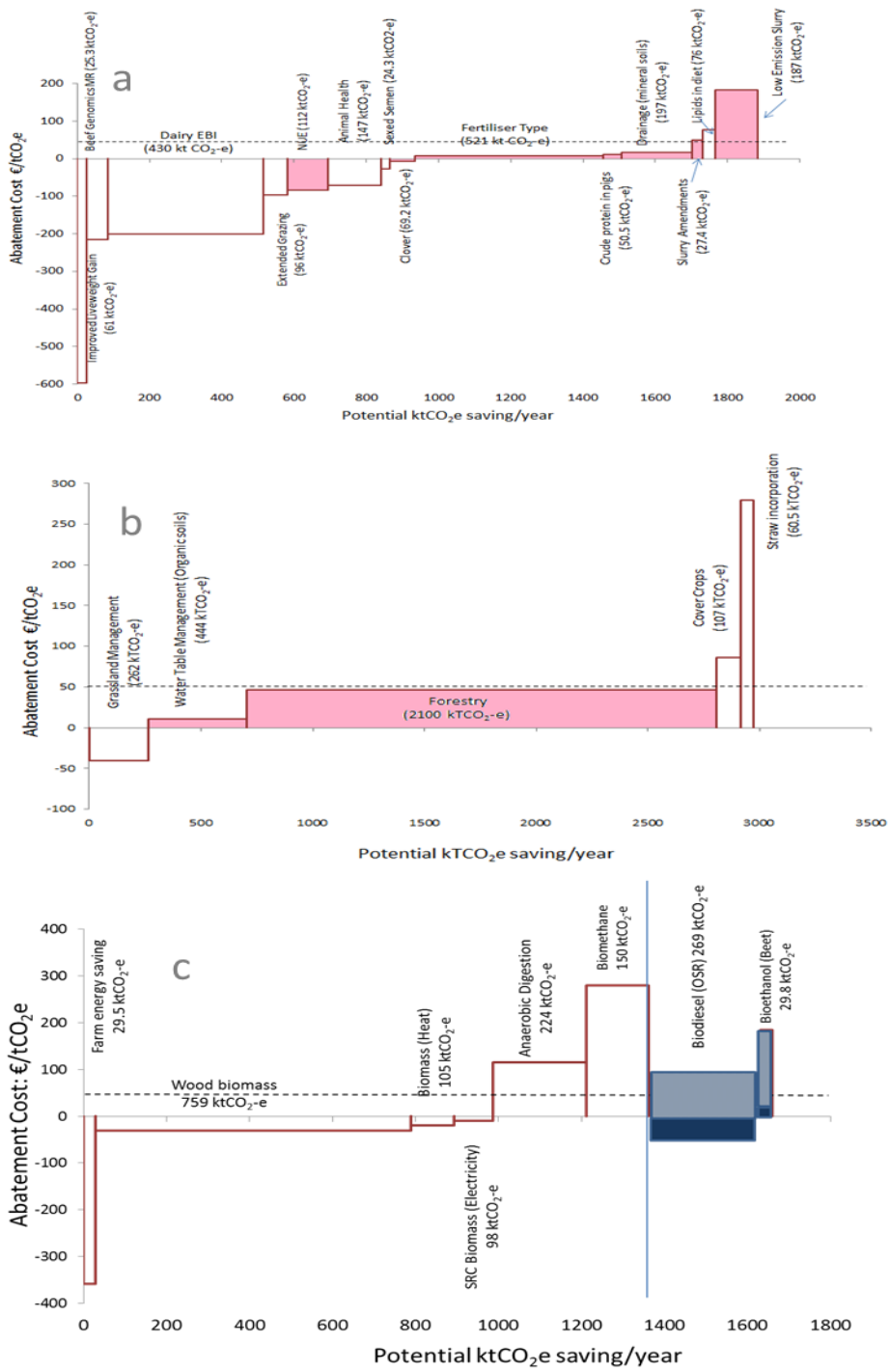

Figure 3: Marginal Abatement Cost Curve for a) CH_4/N_2O from agriculture, b) land-use, c) energy for 2021-2030. Values are based on linear uptake of measures between the years 2021-2030, and represent the mean yearly abatement over this period. Measures principally impacting on methane are indicated in white and N_2O in pink. Dashed line indicates Carbon cost of €50 per tonne CO_2.

4(a) Summary of Research Outcomes

(i) Collaborative links developed during this research

Strong collaborative links have been established between national GHG research groups and also between Irish and UK GHG community via formal links between AGRI-I and the UK GHG Research Platform. In particular, the project has led with the establishment of a standing group to deal with inventory matters between Teagasc, EPA and DAFM. Strong links have also been made with the fertiliser industry.

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

The impact of using novel fertilisers were tested in this project. As a result, KAN (protected urea) is on commercial sale, with 5000 tonnes sold last year.

(iii) Outcomes with economic potential

na

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

The three principal national-level outcomes were:

- *Revised national N_2O emission factors:* This revision had two major impacts. Firstly it removed 750,000 tonnes CO2e from the inventory as dung/urine emissions had been overestimated. Secondly it increased the 'flexibility' of the inventory which means that switching from CAN to protected urea can now be counted as a quantifiable emission reduction measure, with an estimated potential impact of over half a million tonnes CO_2e. Accounting for both the reduction in baseline emissions and the potential mitigation by changing fertiliser type, this equates to 1.25 M tonnes CO_2e. Based on a 2030 base price of €75 per tonne (lower than DPER estimates), this will save the exchequer, almost €94 million per annum in avoided allowance purchase.
- *The generation and publication of the Marginal Abatement Cost Curve analysis:* The MACC analysis has been incorporated into government policy and will be the basis for agricultural mitigation over the next decade.
- Elucidation of movement of soil organic carbon into subsoil layers: This finding will provide the basis of a) future soil C modelling efforts and also may substantially change our understanding of soil C equilibrium post land-use and/or land management change.

4 (b) Summary of Research Outputs

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

<u>Acceptable Format:</u> Walsh, D.R., Murphy, O., Cosgrave, J. (2008). Echinococcosis - an international public health issue. Research in Veterinary Science 774, 891-902.

1. Fox, Aaron, Ikoyi, I., Creamer, R., Lanigan, Gary and Schmalenberger, A. (2017). Microbial community structure and function respond more strongly to temporal

progression than to the application of slurry in an Irish grassland. Applied Soil Ecology 120, 97-104
2. Harty, M., McGeough, K.L., Carolan, R., Muller, C., Laughlin, R.J., Lanigan, G., Richards, K. and Watson, C.J. (2017). Gross nitrogen transformations in grassland soil react differently to urea stabilisers under laboratory and field conditions. Soil Biology Biochemistry 109,23-34
3. Krol, D., Minet, E., Forrestal, P.J., Lanigan, G., Mathieu, O. and Richards, K. (2017). The interactive effects of various nitrogen fertiliser formulations applied to urine patches on nitrous oxide emissions in grassland. Irish Journal of Agricultural & Food Research 56,1 54-64
4. Harty, M.A., Forrestal, P.J., Watson, C., McGeough, K.L., Carolan, R., Elliot, C., Krol, D., Laughlin, R.J., Richards, K.G.and Lanigan, G.J. (2016) Reducing nitrous oxide emissions by changing N fertiliser use from calcium ammonium nitrate (CAN) to urea based formulations. Science of The Total Environment 563, 576-586
5. Khalil, M.I., Abdalla, M., Lanigan, Gary, Osborne, B. and Muller, C. (2016). Evaluation of Parametric Limitations in Simulating Greenhouse Gas Fluxes from Irish Arable Soils Using Three Process-Based Models. Agricultural Sciences 7, 503-520
6. Krol, D., Carolan, R., Minet, E., McGeough, K.L., Watson, C.J., Forrestal, P.J., Lanigan, G. and Richards, K. (2016). Improving and disaggregating N2O emission factors for ruminant excreta on temperate pasture soils. Science of the Total Environment 568, 327-338
7. Jansen-Willems, A.B., Lanigan, G., Clough, T.J., Andresen, L.C. and Muller, C. (2016). Long-termelevation of temperature affects organic N turnover and associated N2O emissions in a permanent grassland soil. Soil 2, 601-614
8. Jansen-Willems, A.B., Lanigan, G., Grunhage, L. and Muller, C. (2016). Carbon cycling in temperate grassland under elevated temperature. Ecology and Evolution 6(21), 7856-78687868 ISSN 2045-7758
9. McGovern E; Kenny DA; McCabe MS; Fitzsimons C; McGee M; Kelly AK; Waters SM, 2018, '16S rRNA Sequencing Reveals Relationship Between Potent Cellulolytic Genera and Feed Efficiency in the Rumen of Bulls', Frontiers In Microbiology 9, http://dx.doi.org/10.3389/fmicb.2018.01842
10. McGovern E; Waters SM; Blackshields G; McCabe MS, 2018, 'Evaluating Established Methods for Rumen 16S rRNA Amplicon Sequencing With Mock Microbial Populations' Frontiers In Microbiology 9, http://dx.doi.org/10.3389/fmicb.2018.01365
11. McGovern E; McCabe MS; Cormican P; Popova M; Keogh K; Kelly AK; Kenny DA; Waters SM, 2017, 'Plane of nutrition affects the phylogenetic diversity and relative abundance of transcriptionally active methanogens in the bovine rumen', Scientific Reports, vol. 7, http://dx.doi.org/10.1038/s41598-017-13013-y
12. Paul, C., Fealy, R., Fenton, O.,, Lanigan G., O'Sullivan L. and Schulte, R.P.O, (2018) Assessing the role of artificially drained agricultural land for climate change mitigation in Ireland. Environmental Science & Policy 80, 95-104
13. Roche, L., Forrestal, P.J., Lanigan, Gary, Richards, K., Shaw, L.J. and Wall, D. (2016). Impact of fertiliser nitrogen formulation, and N stabilisers on nitrous oxide emissions in spring barley. Agriculture, Ecosystems and Environment 233, 229-237

14. Torres-Sallan, G. Schulte, RPO, Lanigan, GJ Byrne,KA, Six,J. Creamer RE. (2017) Clay illuviation provides a long-term sink for C sequestration in subsoils. Nature Scientific Reports 7: 45635.doi: 10.1038/srep45635
15. Torres-Sallan, G.,Creamer R., Lanigan, G., Reidy B., Byrne, K.A. (2018) Effects of soil type and depth on carbon distribution within soil macroaggregates from temperate grassland systems. Geoderma 313, 52-56
16. Zimmermann, J., Carolan, R., Forrestal, P., Harty, M, Lanigan G., Richards K., Roche, L. Jones M.B. (2018) Assessing the performance of three frequently used biogeochemical models when simulating N_2O emissions from a range of soil types and fertiliser treatments. Geoderma 331, 53-69

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

Forrestal P. Fertiliser Nitrogen: C.A.N and Urea as options. Irish Farmers Journal Fertiliser supplement, 29/01/2015

Harty, Forrestal, Watson, Laughlin, Elliot, Lanigan, Richards Nitrogen fertiliser formulation: The impact on grassland yield and gaseous emissions TResearch article Volume 10: Number 1. Spring 2015 pg 10-11

Lanigan, G.J. Reducing greenhouse gas emissions from agriculture: Does it matter? Farming Independent. 25/05/2017

Lanigan, G.TV interview on RTE's PrimeTime. Discuss agricultural GHG emissions and methane. December 2014

Lanigan, G.TV interview on RTE's PrimeTime programme. Discuss the impact of the Paris COP21 Climate Change Conference on Irish agriculture and agricultural GHG emissions November 2015

Forrestal P. 2015 Urea and research update Section in Teagasc Spring Fertiliser Advice

Forrestal, Harty, Roche, Lanigan, Wall, Richards 2016 Meeting with Origin and Gouldings Fertiliser: Research trial work update

Forrestal, Harty, Lanigan, Richards 2016 Teagasc Moorepark Dairy Open Day. Fertiliser Nitrogen: challenges, new options, and solutions

Lanigan, G.J. 2017. Current Agriculture/ Land Use Policy in Ireland. Paper delivered to the Citizens Assembly 4 Nov 2017.

(iii) National Reports

Gary Lanigan, Trevor Donnellan, Kevin Hanrahan, Carsten Paul, Laurence Shalloo, Dominika Krol, Patrick Forrestal, Niall Farrelly, Donal O'Brien, Mary Ryan, Pat Murphy, Barry Caslin, John Spink, John Finnan, Andy Boland, John Upton, Karl Richards 2018. *An Analysis of Abatement Potential of Greenhouse Gas Emissions in Irish Agriculture 2021-2030.* Teagasc Oak Park.

(iv) Workshops/seminars at which results were presented

1. Lanigan, G.J. Current Agriculture/ Land Use Policy in Ireland. Citizens Assembly, Malahide, Nov. 2017 https://www.youtube.com/watch?v=A4F-g52QChw
2. Jansen-Willems, A.B., Lanigan, Gary and Muller, C. CO2 emissions from temperate grassland under elevated soil temperature. Agricultural Research Forum 2015, Tullamore, Co. Offaly, 9th Mar 2015, pg7 33070
3. Harty, Forrestal, Krol, Carolan, Lanigan, Hennessy, McGeough, Laughlin, Watson, Richards Comparing fertiliser nitrogen alternatives to calcium ammonium nitrate: the impact on nitrogen uptake and fertiliser recovery in grassland Agricultural Research Forum, Tullamore, Ireland, 09/03/2015
4. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall. Evaluating the effect of fertiliser nitrogen type on grain yield in spring malting barley Agricultural Research Forum, Tullamore, Ireland, 09/03/2015
5. Harty,McGeough, Müller, Laughlin, Forrestal, Richards and Watson The effect of urea fertiliser formulations on gross nitrogen transformations in a permanent grassland soil. European Geosciences Union General Assembly, Vienna, 12-17th Apr 2015
6. Harty, M., Forrestal, P.J., Carolan, R., McGeough, K.L., Watson, C.J., Laughlin, R.J., Krol, D., Lanigan, Gary and Richards, K. Nitrogen fertiliser formulation: The impact on N2O emissions. European Geosciences Union General Assembly, Vienna, 12-17th Apr 2015
7. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall. Managing the soil nitrate pool in arable systems British Soil Science society early career research conference, 7th-8th April 2015
8. Harty, Forrestal, Lanigan, McNeill, Carolan, McGeough, Laughlin, Hennessy, Elliot, Watson and Richards Calcium Ammonium Nitrate, Urea or Stabilised Urea: The Impact on Yield and Apparent Fertiliser Recovery in Intensive Grassland. Tri-Society International Soil, Crop, Agronomy conference, Minneapolis, USA, 16th - 18th Nov 2015
9. Harty, McGeough, Carolan, Muller, Richards, Laughlin, Watson Fertiliser Formulation Effects on Gross Nitrogen Transformations in Permantent Grassland Soil Tri-Society International Soil, Crop, Agronomy conference, Minneapolis, USA, 16th - 18th Nov 2015
10. Harty, Forrestal, Watson, McGeough, Carolan, Elliot, Krol, Laughlin, Richards and Lanigan. Effect of fertiliser form on yield and gaseous emissions in grassland. Tri-Society International Soil, Crop, Agronomy conference, Minneapolis, USA, 16th - 18th Nov 2015
11. Krol, Forrestal, Lanigan, Richards Can manipulation of the constituents of ruminant urine reduce N2O emissions from urine patches? Tri-Society International Soil, Crop, Agronomy conference, Minneapolis, USA, 16th - 18th Nov 2015
12. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall. Effect of N source and inhibitors on spring barley grain yield Tri-Society International Soil, Crop, Agronomy conference, Minneapolis, USA, 16th - 18th Nov 2015

13. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall. Effect of N source on N2O emissions in spring barley Tri-Society International Soil, Crop, Agronomy conference, Minneapolis, USA, 16th - 18th Nov 2015
14. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall. The effect of N source and N stabilisers on spring barley grain yield International Fertiliser Society Annual Meeting, Cambridge, UK
15. Torres, G., Reidy, B., Lanigan, G., Byrne, K.A. and Creamer, R. Soil carbon sequestration and storage potential of Irish grasslands. Environ 2015, Sligo Institute of Technology, 8-10 April 2015.
16. Torres, G., Reidy, B., Lanigan, G., Byrne, K.A. and Creamer, R. Irish grasslands Carbon sequestration potential. SubSOM 2015- Raesfeld, Germany, 28 April -1 May 2015
17. Torres, G., Reidy, B., Lanigan, G., Byrne, K.A. and Creamer, R. Understanding soil carbon sequestration and storage potential in grasslands. Agricultural Research Forum 2015, Tullamore, Co. Offaly, 9th Mar 2015, pg7 33070
18. Ní Choncubhair, Ó., Osborne, B., Lanigan, G. Carbon balance of renovated grasslands: input- or output-driven? European Geosciences Union General Assembly, Vienna, 12-17th Apr 2015, Oral presentation
19. Lyons, T., Boland, T. and Doyle E. Effect of linseed oil, as an early life dietary supplement, on the ruminal bacterial communities of lambs Proceedings of the Molecular Microbial Group Annual Meeting 2015, Charles Darwin House London 17-18th Dec 2015. pg12.
20. G Torres-Sallan, R Schulte, GJ Lanigan, KA Byrne, B Reidy, R Creamer Deep horizons: Soil Carbon sequestration and storage potential in grassland soils EGU General Assembly Conference Abstracts 18, 14664
21. A Jansen-Willems, G Lanigan, T Clough, L Andresen, C Müller Source portioning of N_ {2} O emissions after long term elevation of soil temperature in a permanent grassland soil EGU General Assembly Conference Abstracts 18, 18388
22. Patrick J Forrestal, David Wall, Rachael Carolan, Mary Harty, Leanne Roche, Dominika Krol, Catherine Watson, Gary Lanigan, Karl G Richards Effects of urease and nitrification inhibitors on yields and emissions in grassland and spring barley International Fertiliser Society AGM Dec 2016
23. E O'Hara, M Zhou, SM Waters, ME Walpole, P Gorka, M Woodbury, GB Penner, LL Guan 0487 Taxonomic assessment of the rumen microbiome of bulls under backgrounding and finishing diets. Journal of Animal Science Supplement (5) 234
24. K Richards, D Selbie, H Di, T Clough, G Lanigan, K Cameron, D Rex, C Watson Evaluation of the N2 emission sources from grazed grassland soils AGU Fall Meeting Abstracts Feb 2016
25. D.J. Krol, R. Carolan, E. Minet, K.L. McGeough, C. J. Watson, M. Harty, C. Elliot, P.J. Forrestal, G.J. Lanigan, K.G. Richards Estimating Tier 2 (country-specific) nitrous oxide emission factors for Irish agriculture International Fertiliser Society AGM Dec 2016
26. Nick A. Owen, Órlaith Ní Choncubhair, Jamie Males, José Ignacio del Real Laborde, Ramón Rubio-Cortés, Howard Griffiths and Gary Lanigan. Eddy covariance

measurements of net C exchange in the CAM bioenergy crop, Agave tequiliana EGU General Assembly Conference Abstracts 18

27. Zimmermann, J., Jones, M.B. Developing a regional scale approach for modelling the impacts of fertiliser regime on N2O emissions in Ireland. EGU General Assembly Conference Abstracts 18
28. D.J. Krol, R. Carolan, E. Minet, K.L. McGeough, C. J. Watson, P.J. Forrestal, G.J. Lanigan, K.G. Richards. Nitrous oxide emissions from urine and dung patches: estimation of national emission factors and possibilities for mitigation. GGAA, Melbourne, Feb 2016
29. D.J. Krol, P.J. Forrestal, G.J. Lanigan, K.G. Richards. Can Manipulation of the Ruminant Urine Constituents Mitigate N2O Emissions from Urine Patches? GGAA, Melbourne, Feb 2016
30. Forrestal, P.J., Krol, D.J., Lanigan, G.J., and Richards, K.G. Chamber size effects on nitrous oxide emissions from simulated urine patches GGAA, Melbourne, Feb 2016
31. P.J. Forrestal, M. Harty, K. McGeough, D. Krol, R. Carolan, G.J. Lanigan, C.J. Watson and K.G. Richards. Fertiliser nitrogen source and stabiliser effects on indirect and total nitrous oxide emissions in temperate grassland GGAA, Melbourne, Feb 2014
32. P.J. Forrestal, E. Minet, D.J. Krol, W. Burchill, G.J. Lanigan, and K.G. Richards. Urine in combination with N fertiliser with and without N inhibitors: effects on pasture system nitrous oxide emissions GGAA, Melbourne, Feb 2015
33. Richards K.G., Harty M., Forrestal P.J., Carolan R., McGeough K, Krol D., Minet E., Laughlin R., Watson C.J., Lanigan G.J. Disaggregated N2O emissions from Irish Agriculture GGAA, Melbourne, Feb 2016
34. M. Harty, K.L. McGeough, R. Carolan, K.G. Richards, P.J. Forrestal , C. Müller, C. Elliot, R.J. Laughlin and C.J. Watson Fertiliser formulation effects on gross nitrogen transformations in permanent grassland soil. GGAA, Melbourne, Feb 2015
35. M. Harty, K.L. McGeough, L. Roche, R. Carolan, P.J. Forrestal, K.G. Richards, C.J. Watson and G.J. Lanigan Proposed improvements to static chamber estimates of Emission Factors. GGAA, Melbourne, Feb 2016
36. P.J. Forrestal, M. Harty, L. Roche, D. Krol, E. Minet, D. Wall, G. Lanigan, K. Richards, R. Carolan, K. McGeough, C. Watson Nitrogen and greenhouse gas emissions in grassland and arable cropping: knowing where we stand and providing solutions CSIRO
37. G. Torres-Sallan, R. Schulte, G. J. Lanigan, K. A. Byrne, B. Reidy, R. Creamer "Question of
38. Quality: Soil Carbon sequestration in deep horizons of Irish Grasslands" Environ
39. Sinead Waters Evaluation of Bovine Rumen Microbial Populations Following Periods of Dietary Restriction and Subsequent Re-alimentation. in 'Host-Microbiome' session. Plant & Animal Genomic Conference 2016, San Diego, California, USA

40. Emily McGovern. Methanogensis in the bovine rumen under conditions of dietary restriction and subsequent compensatory growth. INRA-Rowett Gut Microbiota Symposium, June 22nd 2016, Clermont-Ferrand, France
41. Emily McGovern. Understanding the development and control of stability in the rumen microbiome as a basis for new strategies to reduce methanogenesis. Rumen Stability project meeting, Clermont Ferrand, France. June 24th 2016.
42. McCabe, M., Dewhurst, R., Waters, S., Creevey, C., Cormican, P., Kenny, E. Amplicon Sequencin on the Illumina MiSeq INRA-Rowett Gut Microbiota Symposium 2016, Clermont-Ferrand, France
43. Lyons, T., Boland, T., Doyle, E. Dietary supplementation of lambs in early life, with linseed oil, has a significant effect on their ruminal microbiome structure. Poster and talk of the same title presented at INRA-Rowett Gut Microbiota Symposium 2016, Clermont-Ferrand, France
44. Lyons, T., Boland, T., Doyle, E. Effect of linseed oil, as an early life dietary supplement, on ruminal bacterial communities of lambs. MMEG 2016 Conference, London, UK
45. Lyons, T., Boland, T., Doyle, E. Effect of early life dietary supplementation, with linseed oil, on the ruminal microbiome of lambs. ISME 2016
46. Harty, Forrestal, Krol, Carolan, Lanigan, McNeill, McGeough, Laughlin, Watson, Richards UK Agricultural GHG PLATFORM & Agricultural GHG Initiative for Ireland (AGRI-I) Joint Meeting. *Effect of fertiliser form direct and indirect N2O emissions and on yield in grassland*
47. Harty, Forrestal, Krol, Carolan, Lanigan, McNeill, McGeough, Laughlin, Watson, Richards UK Agricultural GHG PLATFORM & Agricultural GHG Initiative for Ireland (AGRI-I) Joint Meeting: *The impact of fertiliser formulation on NH3 emissions*
48. Carolan,Krol, Forrestal, Minet, Lanigan, Watson, McGeough, Richards 2014 UK Agricultural GHG PLATFORM & Agricultural GHG Initiative for Ireland (AGRI-I) Joint Meeting. *Urine and Dung additions to grassland - N2O*
49. Forrestal, Lanigan, Harty, Roche, Krol, Wall, Minet, Carolan, Laughlin, McGeough, Watson and Richards 2014 UK Agricultural GHG PLATFORM & Agricultural GHG Initiative for Ireland (AGRI-I) Joint Meeting. *Ireland - AGRI-I Grassland and Spring Barley N2O, NH3 and Yield Summary*
50. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall 2014 UK Agricultural GHG PLATFORM & Agricultural GHG Initiative for Ireland (AGRI-I) Joint Meeting *Effect of fertiliser form on N2O emissions in spring barley*
51. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall National Tillage Conference, Kilkenny, Ireland 2015 Evaluating N fertiliser source on spring barley grain yeild
52. Forrestal, Krol, Lanigan, Richards 2015 NORA-ICOS-SITES N2O workshop, Gothenburg, Sweden Urine patch simulation approach: effects on nitrous oxide emissions
53. "Lanigan, Lalor, Forrestal Richards 2015 Global Research Alliance Meeting. Reducing Gaseous Emissions in Irish Agriculture

54. "Harty, Forrestal, Krol, Lanigan, McGeough, Carolan, Laughlin, Watson and Richards
55. " QUB - Molecular Biosciences Postgraduate Symposium Effect of fertiliser form on yield, uptake, direct and indirect N2O emissions in grassland
56. Forrestal, Lanigan, RichardsTeagasc Sheep Open Day, Athenry Fertiliser N & inhibitors
57. Harty: Best Theatre Presentation British Grassland Society Nitrogen fertiliser formulation: The impact on yield and gaseous emissions in temperate grassland
58. Forrestal, Lanigan, RichardsLativian University of Agriculture group visit to Wexford Fertiliser Nitrogen Options
59. Roche, Forrestal, Lanigan, Richards, Shaw, Gooding, Hackett, Wall Catchment Science 2015 Effect of fertiliser N spource on N2O emissions and yield in spring barley
60. Forrestal, Harty, Lanigan, Wall, Krol, Murphy, Hennessy, Carolan, McGeough, McNeill, Laughlin, Watson, Richards Teagasc National Soil Fertility Conference Taking a fresh look at urea preformance in grassland
61. Forrestal Irish Farmers Journal Urea is a viable N source for Irish farms
62. Roche - 2nd place Elevator speech contest, Tri-Society Intl Soil, Crop, Agronomy Conference, Minneapolis, USA, 16th - 18th Nov 2015
63. Roche, Forrestal, Lanigan, Richards, Shaw, Hackett, Wall Teagasc Walsh Fellowship Seminar - Winner Selecting nitrogen fertiliser sources for improved yield and reduced gaseous emissions in spring barley production systems
64. Forrestal Soil and Crop Nutrition level 6 course Johnstown Castle Nitrogen module
65. Torres, Schulte, R., G., Reidy, B., Lanigan, G., Byrne, K.A. and Creamer, R. Poster presentation at Walsh Fellowship Seminar - Winner A question of quality: Soil Carbon sequestration and storage potential of Irish Grasslands
66. Torres, G., Reidy, B., Lanigan, G., Byrne, K.A. and Creamer, R. Presentation at Department of Life Sciences, Postgraduate Research Day, University of Limerick Irish grasslands Carbon sequestration potential
67. Torres, G., Schulte, R., Lanigan, G., Byrne, K.A., Reidy, B.and Creamer, R. Presentation at Soil Science Society of Ireland A Question of Quality: Soil Carbon sequestration at deep horizons of Irish Grasslands
68. Gutzler, C., Donnellan,T., Murphy,P., O'Mara,F., Richards, K. and Schulte, R.P.O. Teagasc response to consultation by the European Commission Consultation on: Integration of agriculture, forestry and other land use into the 2030 EU climate and energy policy framework
69. Gutzler, C. Workshop Workshop by the European Commission. Follow up on consultation and discussion of options for integrating the AFOLU sector into 2030 policy framework
70. Waters, S. M."Sustainable Agri-Food Production and Health - 21st Century Solutions" Delta Edmonton South Hotel, Edmonton, Canada Understanding of the bovine microbiome and its role in feed efficiency and methanogensis
71. McGovern E, O'Hara E, McCabe M, Kenny D and Waters S. M. JPI Workshop, Malaga, Spain Understanding the development of rumen methanogen populations

during key life cycle events in ruminants – the birthing process, weaning and dietary transitions

72. Ní Choncubhair, Ó. Smart Agriculture Internal Workshop, Teagasc, Oak Park: oral presentation Vegetation Indices and Grassland Productivity
73. Ní Choncubhair, Ó., Klumpp, K., Lanigan, G.2016 Animal Change Project Final Meeting, Montpelier, France: oral presentation Measurement and modelling of C balances in grasslands
74. Ní Choncubhair, Ó., Osborne, B., l.anigan, G. UK Agricultural GHG PLATFORM & Agricultural GHG Initiative for Ireland (AGRI-I) Joint Meeting: oral presentation Carbon sequestration in managed grasslands
75. Carolan, R., McGeough, K.L., Higgins, S. and Watson, C.J.Presentation to members of CAFRE and fertiliser industry representatives. Effect of nitrogen fertiliser formulation on dry-matter yield, nitrogen offtake & GHG emissions in grassland

(v) Intellectual Property applications/licences/patents

(vi) Other

Awards:

Harty : Best Oral Presentation AFBI Seminar postgraduate seminar and competition Effect of fertiliser form on yield, uptake, direct and indirect N2O emissions in grassland

Harty: Best Theatre Presentation British Grassland Society Nitrogen fertiliser formulation: The impact on yield and gaseous emissions in temperate grassland

Roche L. - Overall Winner Soil Science Society of Ireland 3 minute thesis competition

Teagasc Walsh Fellow Gold Medal Winner 2014 – Mary Harty

Teagasc Walsh Fellow Gold Medal Winner 2015 Leanne Roche

Teagasc Walsh Fellow Poster Winner 2015 Gemma Torres-Sallan

5. Scientists trained by Project

Total Number of PhD theses: 8

Mary Harty (Queens University Belfast) The impact of fertilizer formulation on N use efficiency and gaseous N emissions in grassland. 2016

Leanne Roche (University of Reading) Assessing different nitrogen fertiliser formulations on spring barley at two sites in the south east of Ireland. 2016

Aaron Fox (University of Limerick) Understanding how the physical fractionation of carbon influences the composition and functionality of soil microbial communities. 2017

Gemma Torres-Sallan (University of Limerick) Physical and biochemical characterisation of soil organic carbon in topsoil and subsoil of Irish grasslands. 2016
Anne Willems (Justus Liebeg University, Giessen) The effect of increased temperature on carbon and nitrogen cycling in grassland. 2017
Tamsin Lyons (University College Dublin) The effects of diet on the ruminal microbiome and interactions between the host immune system and gastrointestinal microbiome as they are established in early life. 2018
Emily McGovern (University College Dublin) An investigation into the relationship between bovine feed efficiency and rumen archaeal and bacterial populations. 2018
Laura Gallego (University College Dublin) Impact of grassland and crop management on CO2 fluxes. 2019

Total Number of Masters theses: 0

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
Teagasc	8	4.2
AFBI	21	5.8
TCD	2	0.9
UCD	2	0.8
UL	2	1.0
Total	**35**	**12.7**

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	6	9.1
PhD students	8	26
Masters students	0	
Temporary researchers	10	1.5
Other		
Total	**24**	**36.6**

8. Involvement in Agri Food Graduate Development Programme

Name of Postgraduate / contract researcher	Names and Dates of modules attended
All PhD's Patrick Forrestal	*Statistical Analysis for Research - (FDSC50040)* *Effective Leadership and Management Skills - (FDSC50010)* *Science Writing and Presenting Skills - (FDSC50050)* *Media Skills for Scientists - (FDSC50020)* *Hot Topics in Agriculture &Food Research - (FDSC50030)* *Innovation & Impact for Scientists - (FDSC50000)*

9. Project Expenditure

Total expenditure of the project: €1,710,242
Total Award by DAFM: €1,698,102

Other sources of funding including benefit in kind and/or cash contribution(specify): €

Breakdown of Total Expenditure

Category	Teagasc	TCD	AFBI	UCD	UL	Total
Contract staff						
Temporary staff						
Post doctorates	243192	105309	131709	0	0	480210
Post graduates	149872	0	0	117409	6857	274137
Consumables	256381	17	126079	42820	3286	428583
Travel and subsistence	96480	794	2187	21950	5730	127141
Sub total	745925	106120	259975	182178	15873	1310072
Durable equipment	2224	0	0	0	2151	4375
Other	0	0	0	0	0	0
Overheads	223778	31836	77993	54653	4762	393022
Total	974700	137956	337968	236832	22786	1710242

10. Leveraging

N/A

11. Future Strategies

Results from the project have been stored in a database. These research results have been utilised in subsequent projects, particularly for modelling. Data have been used in the following projects:
MINE RSF 15 655
AGRI-SOC RSF 17 238
ERA-GAS CEDERS
ERA-GAS MAGGE-PH

12. Consent to Publish Final Report on the DAFM Website and/or Through Other Dissemination channels

I consent to this report being made available to the public, through the Department's website and other dissemination channels.

Yes ☑ No ☐

13. Declaration

I declare that the information contained in this final report is complete and true to the best of my knowledge and belief.

Signed: Project Coordinator

Date: 22/10/2020