Research Stimulus Fund

Final Report

‘Sustainable nitrogen fertiliser Use and Disaggregated Emissions of Nitrogen (SUDEN)’

DAFM Project Reference No: 11-S-138

Start date: 31/10/2015

End Date: 30/06/2016

Principal Coordinator and Institution: Dr. Karl Richards Teagasc Johnstown Castle
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Collaborating Research Institutions and Researchers: Dr Catherine Watson & Dr Ronnie Laughlin (AFBI), Dr. Gary Lanigan, Dr Richie Hackett and Dr Deirdre Hennessy (Teagasc) Professor Christoph Müller (UCD)

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

<table>
<thead>
<tr>
<th>Basic/Fundamental</th>
<th>Applied</th>
<th>Pre Commercial</th>
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Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report:

<table>
<thead>
<tr>
<th>Priority Area (s)</th>
<th>Priority Area I - Sustainable Food Production and Processing</th>
</tr>
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</table>

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

   Ireland’s growing agriculture industry is utilising our national soil and climate resources to produce high quality foods. The production of these foodstuffs underpins an export business worth €10.8 billion in 2015 (Bord Bia, 2016). The sustainability of our production systems are an important point for differentiating our exports from competitors through the efforts of the Bord Bia Origin Green programme for example. Fertiliser nitrogen is a cornerstone input of many of our production systems. However, fertiliser nitrogen application is associated with emissions of the greenhouse gas (GHG) nitrous oxide ($\text{N}_2\text{O}$) and the air pollutant ammonia (NH$_3$). Ireland has committed to making significant reductions in both of these gaseous emissions in the coming years. As agriculture accounts for c. 33% of GHG emissions and c. 98% of ammonia emissions agriculture must play a role in meeting these targets to achieve reductions and to demonstrate contribution to increased sustainability. Fertiliser nitrogen along with dung and urine deposited at pasture are sources of both gases. In the present work ammonia was measured along with yield, N efficiency and nitrate leaching. The greenhouse gas nitrous oxide was measured as part of the sister AGRI-I project, also funded under the Research Stimulus Fund.

2. **Research Approach**

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

   To measure the effect of fertiliser N type on grass yield, NH$_3$ and soil mineral N, replicated field experiments were conducted at three grassland sites in Ireland (Figure 1) in 2013 and 2014 (six site-years). The locations were Johnstown Castle, Co. Wexford, Moorepark, Co. Cork and Hillsborough, Co. Down. The sites were chosen to represent a range of soil and geo-climatic conditions across intensively managed agricultural areas in Ireland. The experimental design was a randomised complete block with five replicates at each site-year. The CAN, urea and urea+NBPT fertiliser treatments were applied at annual N rates of 100, 200, 300, 400 and 500 kg/ha in five equal split applications between March and September. Urea+DCD and urea+NBPT+DCD were applied at the 200 kg N/ha rate only. In addition there was a zero N control treatment. Plots received a basal application of P, K, and S in line with soil test recommendations. Yield and N uptake was measured by harvesting dedicated agronomic plots (2 m x 10-12 m at the end of each grass growth cycle). Soil mineral N was measured by sampling the dedicated soil sampling area of the plots. Ammonia emissions were measured from each of the fertiliser treatments at the Johnstown Castle and Hillsborough sites during 2014 using a system of wind tunnels (Lockyer, 1984; Meisinger *et al.*, 2001). Leaching was measured using the lysimeter facility at Johnstown Castle. Gross N transformations were measured using a $^{15}\text{N}$ stable isotopes coupled with an isotope tracing model. A new model was created joining the Moorepark
dairy simulation model with an environmental model to predict the impacts of FW2025 on Nitrogen emissions.

Figure 1 Experimental setup of one of the three sites in the project.

The spring barley trial was conducted on one free-draining loam site located in Marshalstown and Johnstown Castle Co. Wexford over three years. The experimental design was a randomised complete block with five replicates. The layout of each experimental unit was similar to the grassland sites (Figure 2) with a dedicated N$_2$O, soil mineral N and yield measurement area. The same fertilisers used in the grassland experiment were applied in two split applications. Yield and N uptake was measured by harvesting barley at maturity. Soil mineral N was measured by sampling the dedicated soil sampling area of the plots. Ammonia emissions were measured using a system of luening shuttles.

Ammonia emissions from dung and urine deposition was carried out across three seasons, at the Teagasc Johnstown Castle in Wexford using a system of wind tunnels (Meisinger et al., 2001).

3. Research Achievements/Results

Outline main results achieved

Agronomic Yield

- The yield of CAN and urea was not significantly different in these trials.
- Urea treated with the urease inhibitor NBPT consistently yielded as well as CAN.
The use of the nitrification inhibitor DCD alone decreased grassland yields relative to CAN.

Addition of NBPT to urea treated with DCD recovered the yield lag caused by the nitrification inhibitor.

Efficiency: apparent fertiliser nitrogen recovery (AFR)

- Urea has the potential for lower (AFR) compared to CAN particularly at higher nitrogen rates.
- Use of the urease inhibitor NBPT ensured that the AFR of urea was consistently at least equal to CAN.
- The nitrification inhibitor DCD used alone had a pronounced negative effect on AFR at the inclusion rate tested in these trials. However, inclusion of NBPT with DCD treated urea increased yields to similar levels to yield from plots fertilised with CAN or urea treated with NBPT alone.

Ammonia

- Inclusion of the urease inhibitor NBPT reduced NH\textsubscript{3} losses from urea by 78.5% on average. As a result NH\textsubscript{3} loss from urea+NBPT was not significantly different to CAN.
- Variable ammonia loss is a feature of urea usage, however based on comparing the N recovery in plants fertilised with urea, compared to urea+NBPT or CAN, NH\textsubscript{3} losses are apparently generally low to moderate in temperate Irish grassland and spring barley production.
- Addition of the nitrification inhibitor DCD to urea fertiliser at the rate tested introduces additional uncertainty to the behaviour of urea fertiliser in terms of NH\textsubscript{3} loss.

Nitrate leaching

- There was no significant effect of fertilizer formulation on nitrate leaching under grazing conditions. On average there was 43 kg NO\textsubscript{3}-N ha\textsuperscript{-1} leached in the conventional urea and CAN systems and 37 kg NO\textsubscript{3}-N ha\textsuperscript{-1} leached from the urea with NBPT. There were significant differences in N leaching between soils.

Modelling

- Milk production could be increased by 44% in the high profit grass system compared to the baseline resulting in a farm net profit of €1589 ha\textsuperscript{-1}.
- Incorporation of inhibitors in the high profit grass maintained yield increases of 44% but represented an additional cost of €74 ha\textsuperscript{-1}.
- Increasing milk production increased total N loss to the environment from 107 kg N ha\textsuperscript{-1} (baseline scenario) to a maximum of 162 kg N ha\textsuperscript{-1} for the high profit grass based system.
- Incorporation of inhibitors in the high profit grass system resulted in the lowest total N loss of 122 kg N ha\textsuperscript{-1}, a 44% increase in milk production and increased farm net profit of €1,515 ha\textsuperscript{-1}.

The present study found that the fertiliser N form applied along with enhanced efficiency technologies such as urease and nitrification inhibitors are tools which can help to address
the key challenge of how to continue to apply fertiliser N to underpin crop yields while curtailing reactive N losses. These trials demonstrate that it is possible to achieve important reductions in nitrous oxide emission, particularly in grassland, without cutting N rates or sacrificing yield or fertiliser efficiency. Options to achieve the N$_2$O reductions seen in this study by substituting urea+NBPT or urea+NBPT+DCD for CAN in temperate maritime grassland without compromising yield are rare. CAN is generally more expensive than urea as a N source. The resultant price differential provides scope to add urease and/or nitrification inhibitor technologies to urea and remain cost competitive with CAN. As more urease and nitrification inhibitors and formulations enter the market field testing will remain important to evaluate efficacy and to optimise inhibitor rates to meet economic, agronomic and environmental loss mitigation objectives.

Urea holds a significant cost advantage per kg DM produced because urea is considerably less expensive than either CAN or urea + NBPT. Although less tangible to farmers there was an efficiency penalty, particularly at higher rates, when using urea compared with using CAN or Urea + NBPT. The efficiency disadvantage for urea compared to CAN or urea + NBPT ranged from 4 to 7.6%, a difference likely to be primarily associated with ammonia loss from urea. However, as yield and cost rather than ammonia emissions are currently more pertinent to on farm decisions the yield results of the current study and associated implications for cost per tonne DM production will promote additional urea usage amongst farmers. Such additional usage without a urease inhibitor such as NBPT will present a challenge for national governments committed to reducing national ammonia emissions. Urea + NBPT substitution for CAN is likely to create a small cost saving however there will be a net cost when urea + NBPT is substituted for urea.

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.

This research has identified that farmers can maintain yields and reduce nitrogen loss to the environment by switching from CAN to urea protected with NBPT. This new technology, widely available on the market, offers farmers a cost effective fertiliser that improves on farm sustainability. For the first time this research has generated Irish specific emission factors for dung and urine deposited by grazing cows. The modelling has highlighted that milk production can be increased dramatically through the high profit grass system. Nitrogen loss to the environment can be reduced substantially by integrating inhibitors within the high profit grass system. This research has added to the international scientific community through the publication of a 11 papers and this continues to increase.
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 fertiliser companies producing enhanced efficiency fertilisers. There is on-going work at Johnstown Castle evaluating new urease inhibitors.

(ii) Outcomes where new products, technologies and processes were developed and/or adopted
At the beginning of the project urea protected with a urease inhibitor was not available on the Irish market. In 2016, based on the results of the project there has been adoption of this technology with 194 tonnes of protected urea being sold on the Irish market. The results of the project are being adopted as Tier 2 emissions factors for Ireland by the EPA in the national IPCC reporting.

(iii) Outcomes with economic potential
Urea protected with a urease inhibitor offers a small cost saving to farmers vs the standard CAN fertiliser. However, the results showing comparable yields for urea could lead farmers to pursue these substantial cost savings. This could lead to increased national ammonia emissions.

(iv) Outcomes with national/ policy/social/environmental potential
This project has important national implications. Changing fertiliser N source from CAN to urea protect with a urease inhibitor will sustain yield and efficiency and reduce national greenhouse gas emissions without increasing national ammonia emissions substantially. Increased milk production required by Food Wise 2025 can be achieved through the high profit grass system and nitrogen loss to the environment can be substantially reduced with the incorporation of inhibitors.

4 (b) Summary of Research Outputs

(i) Peer-reviewed publications, International Journal/Book chapters.
1. Forrestal, P.J., Murphy, J.B., Fenton, O. and Richards, K.G. (In Review) Fertiliser formulation and soil type effects on reactive nitrogen leaching in intensive grassland.


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

Contributed paper - international conference

2016


2015


with the nitrification inhibitor dicyandiamide. Ramiran 2015 - 16th International Conference Rural Urban Symbiosis, Hamburg, Germany, 8-10 Sept.


30. Forrestal, P.J., D.J. Krol, G.J. Lanigan, K.G. Richards. Urine patch simulation approach affects quantification of nitrous oxide emissions. 7\textsuperscript{th} International Symposium on Non-CO\textsubscript{2} Greenhouse Gases, Amsterdam, Netherlands, November 2014.


34. Forrestal, P.J., M. Harty, G.J. Lanigan, R. Laughlin, C.J. Watson, K.G. Richards. Assessing ammonia volatilization as influenced by fertilizer nitrogen source, urease,


**2013**


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**Paper/summary in proceedings of national conference**

**2015**


Belfast, Northern Ireland. May 2014.


2013


(iii) National Report


(iv) Workshops/seminars at which results were presented


13
5. **Scientists trained by Project**

Total Number of PhD theses: 2


Total Number of Masters theses: 1


6. **Permanent Researchers**

<table>
<thead>
<tr>
<th>Institution Name</th>
<th>Number of Permanent staff contributing to project</th>
<th>Total Time contribution (person years)</th>
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<tbody>
<tr>
<td>Teagasc Johnstown Castle</td>
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<td>1.96</td>
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<tr>
<td>AFBI</td>
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<tr>
<td>UCD</td>
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<tr>
<td>Teagasc Moorepark</td>
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<td><strong>Total</strong></td>
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<td><strong>5.04</strong></td>
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7. **Researchers Funded by DAFM**

<table>
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<tr>
<th>Type of Researcher</th>
<th>Number</th>
<th>Total Time contribution (person years)</th>
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<tbody>
<tr>
<td>Post Doctorates/Contract Researchers</td>
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<tr>
<td>PhD students</td>
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<td>3.75</td>
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<tr>
<td>Masters students</td>
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<tr>
<td>Temporary field assistants</td>
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<td>2.5</td>
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<tr>
<td>Research Technician</td>
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<td><strong>Total</strong></td>
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<td><strong>9.25</strong></td>
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8. **Involvement in Agri Food Graduate Development Programme**

<table>
<thead>
<tr>
<th>Name of Postgraduate / contract researcher</th>
<th>Names and Dates of modules attended</th>
</tr>
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<tbody>
<tr>
<td>Leanne Roche</td>
<td>Information for hot topics in agri-food research – professional skills for the early career agri-food researcher – September 2013</td>
</tr>
<tr>
<td>Mary Harty</td>
<td>Science Writing - Sept 2014</td>
</tr>
<tr>
<td>Mary Harty</td>
<td>Career Management Skills for the Agri-Food Researcher - Nov 2015</td>
</tr>
<tr>
<td>Dominika Krol</td>
<td>Information for Hot Topics in Agri Food Research - Professional skills for the early-career Agri-Food Researcher</td>
</tr>
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9. **Project Expenditure**

Total expenditure of the project: €635,197.94

Total Award by DAFM: €639,106.01

Other sources of funding including benefit in kind and/or cash contribution(specify): €
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 leverage funds from the Teagasc Walsh Fellowship scheme to support the two PhD students who worked on both this project and AGRI-I. The project led to the successful funding of a Enterprise Ireland Enterprise Post-Doctoral research grant with BASF as the industrial partner. There has also been interest from a number of other large fertiliser manufacturers and there is potential funding in that area in the future. Finally this research has led to involvement in 1 horizon 2020 funding application, one EU ERA-net proposal and one Global Research Alliance funding proposal.

11. Future Strategies

Outline development plans for the results of the research.

There are plans to investigate a number of other advanced fertiliser formulations to assess the potential benefits to optimise production while reducing emissions. There is a need to urgently address the potential issue of residue traces in milk, meat or the
environment. This was beyond the scope of the current project but needs to be addressed to ensure there is no risk to the global marketing of Irish agricultural produce. The model developed in the project will be used in the future for assessment of agronomic and nitrogen losses to the environment.