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

**Research Stimulus Fund**

**Final Report**

# Quantification of the potential of white clover to lower GHG emissions from Irish grassland-based dairy production

**DAFM Project Ref No:** RSF 07 516
**Start date:** 01 December 2007
**End date:** 28 February 2012

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

BASIC/FUNDMENTAL ⟶ APPLIED/PRE COMMERCIAL

| | | |
|---|---|---|
| | X | |

**Key words:** *(max 4)*

Nitrous oxide, grassland, Life cycle assessment, milk production

NDP NATIONAL DEVELOPMENT PLAN

## 1. Rationale for Undertaking the Research

Agriculture is the single largest contributor to greenhouse gas (GHG) emissions in Ireland accounting for nearly 27% of national emissions (McGettigan *et al.*, 2010). The national inventory is compiled using the methodology of the Intergovernmental Panel of Climate Change (IPCC) (IPCC, 1997). Using this approach emissions from agriculture are mainly as methane (62%) and nitrous oxide (38%). Carbon dioxide emissions from agriculture are included elsewhere in the national inventory. Emissions are primarily determined by livestock numbers and mineral fertilizer N (FN) use on farms. Ireland, as a member of the European Union (EU), is committed to a 20% reduction in emissions by 2020 relative to 1990 and achieving this target poses a substantial challenge.

Rhizobia bacteria in association with white clover have the capacity to produce plant-available N in the soil via biological N fixation (BNF), which can replace FN in grassland resulting in lower direct and indirect emissions of nitrous oxide from grassland and thus GHG emissions from pasture-based dairy production. However, there is uncertainty about the potential reduction of soil $N_2O$ emission when FN is partially or completely replaced by BNF in temperate grassland. Furthermore, there is uncertainty about the impact of replacement of FN by BNF on overall GHG emissions from pasture-based dairy production, both on farm and pre-farm (associated with the manufacture of fertilizer N, for example). Grassland accounts for 90% of the agricultural land use in Ireland and grazed grass or grass silage account for 90% of the diet of livestock on dairy farms. The widespread replacement of FN by BNF on Irish farms offers the potential to substantially lower GHG emissions from Irish agriculture while also offering economic benefits to farmers.

The cost of FN has risen substantially during the past decade (Figure 1) and has almost doubled relative to farm-gate milk price, which has contributed to increasing interest in the use of white clover on Irish grassland farms. The results of this work indicate that greater use of white clover on farms can potentially increase the sustainability of grassland-based systems of ruminant livestock production through lower input costs and lower total GHG emissions, but this is dependent on farm efficiency. The results of this research will provide a useful guide to future policy on this aspect of rural development.

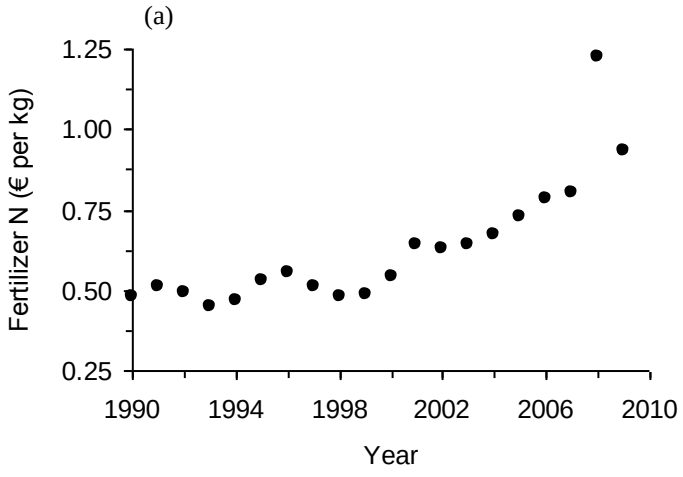


**Figure 1.** (a) Cost of fertilizer N in Ireland between 1990 to 2009

The overall objective of this project was to quantify the potential of white clover to lower GHG emissions from Irish grassland-based dairy production.

The main sub-objectives within this were to:

- Quantify changes in $N_2O$ emissions when BNF is used to replace FN in permanent grassland and evaluate the applicability of the process-based model DNDC to simulate $N_2O$ emissions from Irish grasslands.
- To determine, using LCA, the difference in GHG emissions between BNF and FN-based systems of dairy production on the clay loam soil at Solohead
- To determine, using LCA, the change in GHG associated converting from FN-based to white clover-BNF-based grassland on commercial dairy farms in Ireland.
- To disseminate the outputs of the project to stake holders, policy makers and the scientific community.

## 2. Research Approach

The study to quantify changes in $N_2O$ emissions when BNF is used to replace FN in permanent grassland was conducted at the Solohead Research Farm (52°51'N, 08°21'W) with a poorly drained soil of clay loam texture. The experiment was a randomized block design with five treatments and three replicates. The treatments were: 1) grazed perennial ryegrass (*Lolium perenne*) paddocks receiving 226 kg FN $ha^{-1}$ $yr^{-1}$ (GG+FN), 2) grazed ryegrass/white clover (*Trifolium repens*) paddocks receiving 58 kg FN $ha^{-1}$ $yr^{-1}$ (GWC+FN), 3) grazed ryegrass/white clover paddocks receiving no FN (GWC-FN), 4) perennial ryegrass plots (G-B) and 5) ryegrass/white clover plots (WC-B). G-B and WC-B were not grazed and did not receive slurry or FN and herbage was harvested by mowing. Slurry was applied to GG+FN, GWC+FN and GWC-FN at a rate of 28 $m^3$ $ha^{-1}$ (65 kg N $ha^{-1}$) in February. The area of these paddocks ranged from 0.32 to 1.63 ha. The dimension of each plot was 10m × 10m. Paddocks were rotationally grazed by dairy cows with stocking densities of 2.1 cows $ha^{-1}$ for GG+FN and GWC+FN, and 1.6 cows $ha^{-1}$ for GWC-FN. $N_2O$ fluxes were measured weekly using the static chamber method (Hutchinson & Mosier, 1981) between October 2009 and September 2010. In addition to measurements, the DNDC model was used to simulate $N_2O$ emissions (DNDC 9.3, Li, 2005). Site specific data were used for modelling, including climate data (daily minimum and maximum temperature, rainfall, N concentration in rainfall), soil properties (bulk density, pH, water filled pore space (WFPS) at field capacity and wilting point, clay fraction, soil organic carbon, soil ammonium and nitrate concentration), crop management (including slurry and fertilizer N application, grazing). ANOVA analyses with post hoc LSD tests were performed using PASW Statistics 18 (SPSS Ltd., USA) to identify differences between treatments. Differences with $P < 0.05$ were considered significant.

Life-Cycle Assessment (LCA; ISO, 2006a,b) was used to determine the difference in GHG emissions between BNF and FN-based systems of dairy production on the clay loam soil at Solohead and to determine the contribution of white clover-BNF and other tactical management on commercial dairy farms in Ireland to GHG emissions associated with the milk produced. LCA is an environmental assessment tool that "addresses the environmental aspects and potential environmental impacts throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal, i.e. cradle-to-grave" (ISO, 2006a, b). It was initially developed for industrial and marketing purposes but gradually gained popularity in other fields including agriculture. It has proven to be a valuable tool for the quantification of GHG emissions from farming systems (Thomassen et al., 2008; Garnett, 2009). Unlike IPCC reporting LCA normally reports for a whole system regardless of geographical boundaries and usually reports averaged output based on data representing medium term time periods (e.g. multi-year data). Furthermore, while IPCC methods report emissions per geographical area, LCA results are scaled per "functional unit", which in the case of livestock systems usually means per kg energy corrected milk or per kg meat produced. The LCA approach can be used to explore mitigation options because it is based on a system model and can shed light on the relative importance

of different stages in the supply chain, and on how changes in one part of the system might affect other parts (Garnett, 2009).

Carbon footprint (CF) calculated by life cycle assessment (LCA) was used to compare greenhouse gas emissions from pasture-based milk production based on (i) fertilizer N (FN) and (ii) biological fixation (BNF) in association with white clover (WC) as the main source of plant available soil N. Data were sourced from two system-scale studies conducted at Solohead Research Farm in Ireland between 2001 and 2006 (Humphreys et al., 2008; 2009). Ten FN stocked between 2.0 and 2.5 livestock units (LU) $ha^{-1}$ with fertilizer N input between 173 and 353 kg $ha^{-1}$ were compared with six WC stocked between 1.75 and 2.2 LU $ha^{-1}$ with fertilizer N input between 79 and 105 kg $ha^{-1}$.

In a further study, the CF and land use of energy corrected milk (ECM) produced by 18 Irish commercial dairy farms was analysed based on foreground data from a twelve month survey capturing management tactics and background data from literature.

## 3. Research Achievements

The main conclusions are as follows:

- $N_2O$ emissions due to BNF and clover residual decomposition from permanent ryegrass/white clover grassland were negligible indicating that BNF is not an important source of $N_2O$. This may be as a result of higher N use efficiency for WC-B due to grass-legume interactions and efficient transformation of N into biomass. These results support the exclusion of BNF as a direct source of $N_2O$ from the IPCC methodology.
- Annual $N_2O$ emissions from the two clover based systems were much lower (20 to 23%) than from the fertilized system.
- The process-based DNDC model simulated $N_2O$ fluxes reasonably well when compared with the measured values.
- The results of the LCA of systems at Solohead Research Farm showed that the white clover-based systems (WC) had 11 to 26% lower CF compared with FN (average CF was 0.86 to 0.89 and 1.00 to 1.16 kg $CO_2$ eq/kg Energy Corrected Milk, 91% economic allocation). The biggest difference was between WC and the more intensive FN systems reliant on high input of fertilizer N. Both $N_2O$ and $CO_2$ emissions were lower in WC ($P < 0.001$) while the $CH_4$ emissions per kg Energy Corrected Milk were similar with FN. Ratio sensitivity analysis indicated that the difference was not caused by error due to modeling assumptions. It was concluded that replacing fertilizer N by BFN has the potential to lower the CF of pasture-based dairy production.
- In the study of 18 commercial dairy farms, large variation was found in farm attributes and management tactics, for example, up to a 1.5 fold difference in fertilizer N input was used to support the same stocking density, and up to 3.5 fold difference in concentrate fed for similar milk output per cow. The overall CF of the milk production from the 18 dairy farms was 1.23 ± 0.16 kg $CO_2$ eq/kg ECM and overall land use was 1.22 ± 0.22 $m^2$ per kg ECM. Effective sward management of clover within a few farms lowered the CF but increased on-farm land use. It was concluded that a combination of multiple tactics determines CF and land use of milk production on commercial dairy farms and that farm efficiency is critical to yield benefits from specific tactical management.
- Much of this research is published or is in the process of being published in the scientific literature and conference proceedings.

## 4. Impact of the Research

Using the same datasets as those used in the present project, Humphreys *et al*., (2012) compared the profitability of systems of dairy production based on N fertilized grass (FN) and grass-white clover (WC) grassland and assessed sensitivity to changing fertilizer N and milk prices. Stocking density, milk and total sales from WC were approximately 0.90 of FN. In scenarios with high fertilizer N price combined with intermediate or low milk prices WC was more ($P$<0.05) profitable than FN. Projecting into the

future assuming similar trends in fertilizer N and milk prices to that in last decade, this analysis indicates that WC will become an increasingly more profitable alternative to FN for pasture based dairy production. The results of the present study show that WC can result in lower direct emissions of $N_2O$ and had 11 to 26% lower GHG emissions estimated using LCA compared with FN. The main potential advantages of clover from the perspective of GHG abatement are (i) it allows dairy farmers to achieve the same net income at lower stocking densities (less N cycling within the system and lower urine deposition under grazing) compared with a higher stocked system reliant on high inputs of fertilizer N, (ii) lower fertilizer N input causes lower direct and indirect emissions of $N_2O$ associated with the application of fertilizer N, (iii) lower fossil energy required to produce N fertilizers and (iv) direct $N_2O$ emission from BNF per se was shown in the present study to be negligible and the $N_2O$ emissions induced by the growth of legume crops/forages may be estimated solely as a function of the above-ground and below-ground nitrogen inputs from crop residues..

## 5. Exploitation of the Research

Clover as an option for lowering GHG emissions from Irish agriculture was included in the Teagasc submission in January 2011 entitled "Irish Agriculture, Greenhouse Gas Emissions and Climate Change: opportunities, obstacles and proposed solutions" and edited by R.P.O. Schulte and G. Lanigan. 93 pages.

The work was included in the submission and presentation "Livestock Production and the abatement of agricultural GHG Emissions" by Prof. Nicholas M. Holden at the National Economic and Social Council Workshop "Climate Change-Meeting Ireland's 2020 Obligations" held at UCD on 16th May 2012.

## 6. Summary of Research Outputs

**(a) Intellectual Property applications/licences/patents**

1.
2.

**(b) Innovations adopted by industry**

1.
2.

**(c) Number of companies in receipt of information**

**(d) Outcomes with economic potential**

1.
2.

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

1. Both the measured and simulated results supported that there was a clear reduction of GHG emissions when FN was replaced by BNF.

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

1. Li DJ, Lanigan G, Humphreys J, 2011, Measured and simulated nitrous oxide emissions from ryegrass- and ryegrass/white clover-based grasslands in a moist temperate climate. *Plos One*, doi: 10.1371/journal.pone.0026176.
2. Yan M-J., Humphreys J. and Holden N.M. (2011) An evaluation of life cycle assessment of European milk production. *Journal of Environmental Management*, Volume **92**, Issue 3, 372-379.
3. Yan, M.-J., Humphreys, J., Holden, M.N. The carbon footprint of pasture based milk production: can white clover make a difference? Submitted to Journal of Dairy Science
4. Yan, M.-J., Humphreys, J., Holden, M.N. LCA of milk production from commercial dairy farms: the influence of management tactics. Submitted to Journal of Dairy Science
5. Yan, M.-J., Humphreys, J., Holden, M.N. Evaluation of Input-Output and process based LCA of Irish milk production. To be submitted to International Journal of Agricultural sustainability.

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

1. Li, D., Lanigan G. and Humphreys J. (2011) Use of white clover to lower soil $N_2O$ emissions from temperate moist grassland. *Agricultural Research Forum*, page 68. The Tullamore Court Hotel, 14-Mar-2011.
2. Li DJ, Lanigan G, Humphreys J, (2011) Use of white clover to lower soil $N_2O$ emissions from temperate moist grassland, Oral presentation at the 'Nitrogen & Global Change' conference, Edinburgh, UK, April 11-14, 2011.
3. Yan, M-J., Humphreys, J. and Holden, N.M. (2012) Life Cycle Assessment of Irish milk production. Oral presentation at 2012 Sino-European Symposium on Environment and Health (SESEH), Page 54. August 20 - 25, 2012, Galway, Ireland.
4. Yan, M-J., Humphreys, J. and Holden, N.M. (2012) Carbon footprint of Irish milk production. In: Proceedings from 17th international Nitrogen Workshop, 26-29 June 2012, pages 404-405. (Oral presentation).
5. Yan, M-J., Humphreys, J. and Holden, N.M. (2012) Carbon footprint of Irish milk production: can white clover make a difference? In: Proceedings from 17th international Nitrogen Workshop, 26-29 June 2012, pages 409-410.
6. Yan, M.-J, Humphreys, J. and Holden, N.M.(2012) Carbon footprint of Irish milk production. 8th International Conference on LCA in the Agri-Food Sector, Rennes, France, 2-4 October 2012 (in press).
7. Yan, M-J., Humphreys, J. and Holden, N.M (2012) Carbon footprint of Irish milk production. Oral presentation at the annual meeting of American Society of Agricultural and Biological Engineers (ASABE), Jul 29 - Aug 1st 2012, Texas, USA
8. Yan M.-J., Humphreys J., Holden N. M. (2011) Life cycle comparisons of greenhouse gas emissions from pasture-based milk production of Ireland. Agriculture Research Forum. 14th-15th March 2011. *Agricultural Research Forum*, page 65. The Tullamore Court Hotel, 14-Mar-2011.
9. Yan, M-J., Humphreys, J. and Holden, M.N. (2010) Life cycle comparisons of greenhouse gas emissions from pasture-based dairy production of Ireland. Proceedings of VII International conference on Life Cycle Assessment in the agri-food sector Bari, September 2010, 22-24.
10. Yan M., Humphreys J., Holden N.M. (2010) Methods and results of research on GHG emissions from dairy farms in Ireland. Invited speech at EGF (European Grassland Federation) pre-conference workshop 'Green effects of dairy farming', August 29, 2010, Kiel, Germany.

11. Yan M., Humphreys J., Holden N.M. (2009) LCA studies: how comparable are they? Examples of milk production in Europe, New Zealand and Canada. Oral presentation at the 2nd Chinese Conference on Life Cycle Management, Nov 15-16, 2009. Beijing, China.

12. Yan M., Humphreys J., Holden N.M. (2009) Reducing the carbon footprint of Irish dairy farming. Poster presented at AgMet Group 25th Anniversary meeting, Dec 7, 2009, Dublin, Ireland.

13. Yan M.-J., Humphreys J., Holden N. M. (2009) Life cycle comparisons of greenhouse gas emissions from pasture-based dairy production in Ireland. *Irish Journal of Agricultural and Food Research*, 48, 275.

**(h) National Report**

1. Humphreys, J., Li D, Yan M, Lalor, S., Hyde, B., Lanigan, Gary, Holden, N. and Watson, C. (2010). The role of N-efficiency in lowering nitrous oxide emissions from agriculture in Ireland. In: Proc. 'A Climate for Change' - Opportunities for carbon efficient farming, Mansion House, Dublin, 24-Jun-2010, p23-24.

**(i) Popular non-scientific publications**

1.
2.

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

1. There were presentations about tasks 1 and 2 of this project at the international conference entitled 'Forage Legumes in Temperate Pasture-based systems' conference visit to Solohead farm on 16 October 2009.

2. There was a presentation about this project at the Teagasc Agri-environment Conference 2010 which took place on 7 September in Ballykisteen Hotel, Tipperary with a visit to Solohead Research Farm in the afternoon.

3. A workshop was held at UCD as part of the Innovation Dublin 2010 Festival, aiming at the small business who is seeking a green image to customers and was received good claim. Presentation title: Start life cycle thinking today. November 12, 2010. Please note the website not longer exists and the cache has been saved and attached as "webpage backup.pdf

4. A presentation of the results to date was made to the dairy farmers involved in this project at Moorepark Research and Innovation Centre on 12 April 2011 and on 24 July 2012.

5. Three presentations about this project were made at the Fourth General Meeting of the Dairyman project which visited Solohead Research Farm and two of the dairy farms involved in this project on 19 April 2011.

## 7. Permanent Researchers

| Institution Name | Number of Permanent staff contributing to project | Total Time contribution (months) | Average time contribution per permanent staff member |
|---|---|---|---|
| Teagasc | 4 | 23.86 | 5.96 |
| UCD | 1 | 3.60 | 3.60 |
| **Total** | **5** | **27.46** | **9.56** |

## 8. Researchers Funded by RSF

| Type of Researcher | Number | Total Time contribution (months) | Average time |
|---|---|---|---|
| Post Doctorates | 1 | 21.36 | 21.36 |
| Contract Researchers | | | |
| PhD postgraduates | 1 | 43.20 | 43.20 |
| Masters postgraduates | | | |
| Temporary researcher | 1 | 9.00 | 9.00 |
| Other | | | |
| **Total** | **3** | **73.56** | **73.56** |

## 9. Postgraduate Research

Total Number of PhD theses: __1__

Ming-Jia Yan submitted her thesis entitled “Life Cycle Assessment of Irish Milk Production” to the National University of Ireland (University College Dublin) 0n July 3rd 2012. Her viva took place on 17 August 2012 and the thesis was passed subject to minor corrections.

Total Number of Masters theses: __0__

## 10. Project Expenditure

Total expenditure of the project: €395,079.00

Total Award by RSF €395,048.98

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

Breakdown of Total Expenditure

| Category | Teagasc Moorepark | Teagasc Johnstown Castle | University College Dublin | Name Institution 4 | Total |
|---|---|---|---|---|---|
| Contract staff | 99,689.48 | 0.00 | 0.00 | | 99,689.48 |
| Temporary staff | 0.00 | 0.00 | 19,562.98 | | 19,562.98 |
| Post doctorates | 0.00 | 0.00 | 93,771.93 | | 93,771.93 |
| Post graduates | 0.00 | 0.00 | 54,099.94 | | 54,099.94 |
| Consumables | 16,566.53 | 0.00 | 0.00 | | 16,566.53 |
| Travel and subsistence | 4,546.70 | 2,696.53 | 8,423.41 | | 15,666.64 |
| Sub total | **120,802.71** | **2,696.53** | **175,858.26** | | **299,357.50** |
| Durable equipment | 0.00 | 0.00 | 5,319.16 | | 5,319.16 |
| Other | 0.00 | 1,889.75 | 923.40 | | 2,813.15 |
| Overheads | 34,022.77 | 808.96 | 52,757.46 | | 87,589.19 |
| **Total** | **154,825.48** | **5,395.24** | **234,858.28** | | **395,079.00** |

## 11. Future Strategies

In September 2009, Teagasc was granted Interreg NWE funding for the Dairyman Project (096D). Improving regional prosperity through better resource utilization on dairy farms and stakeholder cooperation (DAIRYMAN; 2009-2013). Funded by INTERREG IVB NWE 096D. Work in task 3 was closely linked with work in work package 2 in the Dairyman Project: http://www.interregdairyman.eu/

In April 2010 Teagasc was granted FP7 funding for a project known as LEGUME FUTURES: Legume-supported cropping systems for Europe (LEGUME FUTURES): evaluating the potential of legumes in farming systems to improve profitability and lower environmental impact (2010-2013). Funded by FP7 GA no. 245216 CP-FP. This FP7 project builds on the work being conducted in this project in task 1. Details of this project are available: http://www.legumefutures.eu/

Teagasc is a partner in FP7 project Crops and Animals Together (2011-2014), which is concerned with innovative farming systems for optimized use of energy and nutrients on farms. The grant agreement (no. 289328) was signed in November 2011. The first project meeting took place in Rennes on 29 February 2012. Teagasc's involvement in this project grew out of the three tasks in this RSF project.

## 12. Industry Collaboration

Teagasc has recently signed a contract with Carbery Group to conduct LCA of 12 of their dairy suppliers. John Joe O'Sullivan is a Carbery supplier involved in this RSF project. Carbery Group contacted us on the basis of the measurements we were making on his farm and the project 'Carbery Greener Dairy Farms' grew out of this initial contact. Funding from a commercial company is a clear sign of the relevance of this work to industry. Carbery are specifically interested in a Sustainability Audit of their farms, which will include C footprint among other measurements.