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# Accounting for nitrogen (N) in a pasture-based system of dairy production at Solohead Research Farm

Key external stakeholders:
Policy makers, research scientists, farming community

Practical implications for stakeholders:
Only a relatively small proportion (15 to 35%) of N entering dairy farms is retained in agricultural products; the remainder is lost from the system. Regulations implemented under the Nitrates Directive, the Water Framework Directive, National Emissions Ceilings Directive and our commitment to meet national greenhouse gas (GHG) mitigation targets puts pressure to account for reactive N lost from dairy farms. This study showed that 33% of N entering the farm was retained in products (milk, cull cows and calves), only 9% was lost to water, 3% was lost as nitrous oxide (which is a potent greenhouse gas), 29% was lost as ammonia (an important transboundary gas) and 24% was lost as environmentally benign dinitrogen ($N_2$). The new knowledge is the quantification of the proportion lost as $N_2$. The main implication of this study is that it allows us to have confidence in our estimates of where N is being lost from pasture-based dairy farms by various pathways.

## Main results:

- The total amount of N entering the system in fertilizer, feed and biological N fixation was 250 kg/ha.
- Of the N entering the system 33% was retained in products (milk, cull cows and calves), 9% was lost to water, 3% was lost as nitrous oxide (which is a potent greenhouse gas), 29% was lost as ammonia (an important transboundary gas) and 24% was lost as environmentally benign dinitrogen ($N_2$).
- The new knowledge is the quantification of the proportion lost as $N_2$ and the simultaneous accounting for the total N exiting the system.
- This study highlights the relatively low proportion of the N that was lost to water and the high proportion of the N lost as ammonia.
- This study also emphasises that the focus should be on ammonia and nitrous oxide to minimise environmentally damaging N losses from pasture-based dairy production systems on heavy soil.

## Opportunity / Benefit:

- The main benefit of this study is that it allows us to have confidence in our estimates of the N being lost from pasture-based dairy farms by various pathways because the total N entering the system was accounted for in N exiting the system.

## Collaborating Institutions:

Trinity College Dublin, University College Dublin



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## • Project background:

- Only a relatively small proportion (15 to 35%) of N entering dairy farms is retained in products; the remainder is lost from the system. Regulations implemented under the Nitrates Directive, the Water Framework Directive, National Emissions Ceilings Directive and our commitment to meet national greenhouse gas mitigation targets puts pressure to account for N lost from dairy farms.
- This study aimed to close some important gaps in the knowledge of N flows in Irish pasture based dairy production on heavy soils. In similar studies in the past there was always a large proportion of N entering the system that remained unaccounted for.
- This study, which is the first of its kind, simultaneously accounted for all N exiting the system in product (milk, cull cows and calves) or as losses to the environment.

## 1. Questions addressed by the project:

- Quantify $N_2O$ emissions from grassland over a four-year period (2009 to 2012)
- Quantify the extent of biological $N_2$ fixation by white clover as an input to the system in 2011 and 2012
- Quantify the effect of varying levels of fertilizer N input on biological $N_2$ fixation by white clover
- Quantify $N_2$ emissions from grassland in 2011 and 2012
- Compile a farm N balance sheet by quantifying all N entering and existing from the farm in 2011 and 2012.
- Compile a farm N balance sheet over an 11 year period (2001 to 2012) by combining previously published data and predictive relationships developed in the current study

- Nitrous oxide ($N_2O$) emissions are subject to intra- and inter-annual variation due to changes in weather and management. This creates significant uncertainties when quantifying estimates of annual $N_2O$ emissions from grazed grasslands. Despite these uncertainties, the majority of studies are short-term in nature (<1 year) and as a consequence, there is a lack of data on inter-annual variation in $N_2O$ emissions. The objectives of one study were to (i) quantify annual $N_2O$ emissions and (ii) assess the causes of inter-annual variation in emissions from grazed perennial ryegrass/white clover grassland. Nitrous oxide emissions were measured from fertilized and grazed perennial ryegrass/white clover grassland (WC) and from perennial ryegrass plots that were not grazed and did not receive N input (GB), over 4 years from 2008 to 2012 in Ireland (52°510N, 08°210W).
- The objectives of a second study were to compare techniques for measuring biological nitrogen fixation (BNF) and to assess how fertiliser N input affects the balance between BNF and sustainable herbage production on perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) grassland. Biological N fixation and herbage production by white clover based grassland was measured in 2011 and 2012 under four nominal annual fertiliser N inputs: 0 (0N), 86 (86N), 140 (140N) and 280 kg $ha^{-1}$ (280N). Biological N fixation was measured using the $^{15}N$ isotope dilution and $^{15}N$ natural abundance techniques under all fertiliser N inputs and also using the nitrogen difference technique under 0N.
- A small proportion (15-35%) of nitrogen (N) input to pasture-based livestock production systems is converted to saleable agricultural products. The majority of remaining N (surplus N) is largely unaccounted for. While some surplus N is retained in the system, which can be beneficial, most is lost through a range of pathways with potential environmental consequences. The objectives



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of this study were to (i) account for all N inputs into and outputs from a pasture-based dairy system and (ii) determine the relative importance of the components of this balance sheet. Detailed measurements and estimates of N flows and fluxes were carried out on a pasture-based dairy production system in Ireland (52°51'N, 08°21'W) in 2011 and 2012.

## 3. Main results:

- In the first study the annual $N_2O$-N emissions (kg $ha^{-1}$; mean ± SE) ranged from 4.4 ± 0.2 to 34.4 ± 5.5 from WC and from 1.7 ± 0.8 to 6.3 ± 1.2 from GB. Inter-annual variation in $N_2O$ emissions was attributed to differences in annual rainfall, monthly (December) soil temperatures and variation in N input. Such substantial inter-annual variation in $N_2O$ emissions highlights the need for long-term studies of emissions from managed pastoral systems.
- In the second study the two $^{15}N$ techniques produced similar annual estimates of above-ground BNF across the range of fertiliser N inputs. Fertiliser N input resulted in higher herbage dry matter yield, but reduced annual BNF which averaged 80, 64, 66 and 47 kg $ha^{-1}$ on 0N, 86N, 140N and 280N, respectively, across both techniques and years. Inter-annual variation in BNF was substantial with 2- to 3-fold differences between 2011 and 2012. This was attributed to variation in clover DM yield due to differences in weather conditions between years.
- Total N inputs were 250 kg $ha^{-1}$ and outputs were 269 kg $ha^{-1}$, the latter being comprised of exports in products: 79 kg $ha^{-1}$ and environmental losses: 190 kg $ha^{-1}$ averaged over both years. Farm N balances (mean ± 95% confidences intervals) where -50 ± 82 kg $ha^{-1}$ in 2011 and 1 ± 22 kg $ha^{-1}$ in 2012 and , hence, came close to a balance between inputs and outputs despite large uncertainly around these values. Of N lost by various pathways, 6.1% was lost to groundwater, 41.6% as ammonia (estimated), 8.0% as nitrous oxide and 43.7% as dinitrogen gas.

## 4. Opportunity/Benefit:

- Although N surpluses on pasture based livestock production systems can be substantial, the results of this study suggest that a high proportion of surplus N may be lost as environmentally benign dinitrogen gas. This study also highlights where the emphasis should be (ammonia and nitrous oxide) in terms of minimising environmentally damaging N losses and improving the N-efficiency of such systems of dairy production.

## 5. Dissemination:

### Main publications:

Burchill, W., Li, D., Lanigan, G., Williams, M. and Humphreys, J. (2014) Inter-annual variation in nitrous oxide emissions from perennial ryegrass/white clover based grassland used for dairy production. Global Change Biology. 10, 3137-3146, DOI: 3110.1111/gcb.12595.

Burchill, W., James, E., Li, D., Lanigan G.J., Williams, M., Iannetta, P. and Humphreys, J. (2014). Comparisons of biological nitrogen fixation in association with white clover (trifolium repens L.) under four fertiliser nitrogen inputs as measured using two 15N techniques. Plant and Soil. 385, 287-302, DOI 10.1007/s11104-014-2199.

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2016) A system N balance for a pasture-based system of dairy production under moist maritime climatic conditions. Agriculture, Ecosystems and Environment (in press).

### International conferences

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2013). Comparisons of biological N fixation of white clover under four fertiliser nitrogen inputs measured using two 15N techniques. Poster presented at the Sustainable intensification conference: Pathway to low carbon farming. Edinburgh, Scotland.

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2013). Inter-annual variation in nitrous oxide emissions from white clover based grassland used for dairy production. Poster presented at the proceedings of the Greenhouse Gasses and Animal Agriculture Conference. UCD, Dublin.



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Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2013). Nitrous oxide emissions from white clover based grassland used for dairy production. Paper presented at the proceedings of the 17th European Grassland Federation Symposium 2013. pp 79-81 Akureyri, Iceland.

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2012) Nitrous oxide emissions from white clover based grassland used for dairy production under moist maritime climatic conditions. Paper presented at the proceedings of the 12th Congress of the European Society of Agronomy. pp 214-215. Helsinki, Finland.

### National Conferences and seminars

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2013). Nitrous oxide emissions from white clover based grassland used for dairy production. Paper presented at the proceedings of the Agricultural Research Forum, pp. 22 Tullamore, Ireland.

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2012). Accounting for N losses in dairy production at Solohead Research Farm. Paper presented at the proceedings of the Agri-Environment Conference 'Sustainable Pathways to Food Harvest 2020'. pp 23-24. Dublin, Ireland.

### Research article

Burchill, W., Lanigan, G., Li, D., Williams, M. and Humphreys, J. (2013) Nitrous oxide production from Irish grassland. TResearch, Volume 8: number 2. Summer 2013. pp 28-29: Teagasc.

## 6. Compiled by: Dr James Humphreys



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