Title	Atmospheric Nitrogen Pollution: Sources, Impacts and Solutions
Publication date	2017-05
Publisher	University College Dublin
Item record/more information	http://hdl.handle.net/10197/9150

UCD School of Biosystems and Food Engineering

Atmospheric Nitrogen Pollution: Sources, Impacts and Solutions

Workshop Summary

UNIVERSITY COLLEGE DUBLIN

BELFIELD, DUBLIN 4, IRELAND

May 2017

Editors: David Kelleghan, Michelle Savian, Mark Sutton, David Dodd, Thomas P. Curran.

E-mail david.kelleghan@ucdconnect.ie

Web site http://www.ucd.ie/ammonian2k

Contents

Acknowledgements

The editors wish to thank the contributions of the early career researchers who presented on the day and contributed to the completion of this document, namely Brian Doyle, Ian Kavanagh, Aneesh Kale, Conor Bracken, Stuart Kirwan, Antonio Cachinero Vivar and Dr. Jim Johnson. A special thanks to Dr. Gary Lanigan for his time and effort is also required.

The editors would also like to thank Sinead Macken of the Environmental Science Association of Ireland and Annette Patchett of the School of Biosystems and Food Engineering, without whom the event would not have taken place. Funding and administrative support from the Environmental Sciences Association of Ireland (http://www.esaiweb.org/), the Environmental Protection Agency (https://www.epa.ie/) and UCD School of Biosystems and Food Engineering (http://www.ucd.ie/biosystems/) are gratefully acknowledged. A special thanks to Jeremy Emmett-Booth for his time and expertise taking photographs.

Introduction

Every year, the Environmental Protection Agency (EPA) and the Environmental Science Association of Ireland (ESAI) have an open call for Grassroots workshops. These are aimed at encouraging early career researchers to organise workshops relevant to the EPA and ESAI. Grassroots Workshops are an excellent opportunity for early career researchers to disseminate their work and encourage knowledge transfer, ideally establishing new collaborations. This year, a PhD student, David Kelleghan, in UCD School of Biosystems and Food Engineering was successful when applying to organise a workshop. David is a PhD student researching gaseous emissions and their environmental impact as part of the AmmoniaN2K project in the school. He ran a workshop entitled "Atmospheric Nitrogen Pollution: Sources, Impact and Solutions" in UCD on May 19th, 2017. The event hosted three keynote speakers, namely Prof. Mark Sutton of the Centre of Ecology and Hydrology, in the United Kingdom; Dr. Gary Lanigan of Teagasc and David Dodd of the Department of Communications, Climate Action and Environment.

The workshop was aimed at gauging the current level of knowledge in Ireland regarding the potential impacts and sources of atmospheric nitrogen pollution. With the new targets under the National Emissions Ceilings (NEC) Directive from the European Union, highlighting the need for a cost effective risk based approach for monitoring air pollution on sensitive ecosystems, this workshop proved timely and facilitated discussion between key stakeholders, international experts and both experienced and early career researchers. This allowed for an open frank discussion about both ongoing research and where this work needs to go in the future.

David Kelleghan addresses attendees, opening the workshop.

The EPA/ESAI Grassroots Workshop Support Scheme provides funding to postgraduate and postdoctoral researchers to organise stand-alone workshops, in the broad environmental research area, that fall within the remit of the ESAI and EPA. Contact administrator@esaiweb.org for further information.

Keynote Speakers (In order of appearance)

David Dodd - Department of Communications, Climate Action and Environment.

David Dodd is an environmental scientist with nearly 20 yrs. experience within the field. He spent 10 years working within the Environmental Protection Agency, and is currently a scientific technical policy officer within the Department of Communications, Climate Action and Environment (DCCAE). He is currently working on Ireland's first clean air strategy which aims to reduce emissions across all sectors following an examination of sources.

Presentation Summary: David gave an overview of the work the Department is doing working towards the first Clean Air Strategy. He referred to the smoky coal ban, which has significantly improved air quality in Dublin, and has since spread to other cities and towns across Ireland. He highlighted the need for new legislation and programmes to tackle the growing issue of nitrogenous and other air pollutants. The consultation period was launched on the 1st of March focusing on residential, transport, agriculture, energy and industry. Clean Air is vital to public health and also good environmental quality. A key part of meeting World Health Organisation targets is a switch from using polluting fuels to low smoke, low carbon fuels and alternative technologies. For example, 30 to 50% of new house builds have no chimneys, because regulations are pushing for alternative technologies. Ireland will need to reduce emissions in order to achieve national emission ceilings targets. A revised EU National Emissions Ceiling Directive is currently being transposed into Irish law, which set ceilings for a range of pollutants including ammonia (NH_3), Particulate Matter (PM), nitrogen xxides (NO_x), etc. Premature mortality figures in Ireland in relation to air pollution can reach 1600 per year, primarily due to PM; there may also be links to nitrogen dioxide (NO_2) and ozone (O_3). An example of secondary impacts of air pollution is that of economic cost, if an individual is sick, they may not be able to work or have reduced productivity, in combination with increased hospital admissions.

Food Wise 2025, a campaign aiming at increasing production in the agricultural area needs to take cognisance of both environmental and health impacts associated with increasing air pollution. There is also a need to reduce impacts from Irelands transport sector. Ireland currently does not have a permanent ammonia monitoring network, which is required in order to monitor trends similar to the United Kingdom. Burning fuels for domestic heating in rural areas also contributes to the production of PM. More than 95% of atmospheric ammonia arises from agriculture, with a smaller amount coming from catalytic convertors in cars, and from sewage. NO_2 is also produced by the agricultural sector, primarily from fertilizer use. Land clearance and land burning is a significant issue, with recent gorse fires visible on satellite imagery, they can have significant contributions to local air pollution.

The clean air strategy suggested a ban on splash plate spreading of slurry could be considered as a method for reducing ammonia and greenhouse gas emissions from slurry spreading. Anaerobic digestion is another useful alternative to land spreading, an issue with its delayed implementation in Ireland may be due to its tariff, which is currently set at 15 cents per kilowatt hour, whereas in Northern Ireland, it is close to 25 pence per kilowatt hour. Solutions to issues raised by transport include electrification, cleaner transport fuels, rebalancing the tax for diesel or petrol, new real world driving emission regulations, and enhancing Irelands cycling infrastructure.

Prof. Mark Sutton – Centre of Ecology & Hydrology

Prof. Sutton's research focuses on the emission, behaviour and fate of ammonia in the atmosphere. The largest aspect of the work has concerned the measurement of ammonia biosphere-atmosphere exchange with terrestrial ecosystems, resulting in new conceptual and quantitative models. Prof. Sutton has developed a suite of tools to quantify the impacts of ammonia over the UK for DEFRA and other government organisations, including the 'FRAME', 'SCAIL' and 'EMEP4UK' models, and the National Ammonia Monitoring Network.

Prof. Sutton has been researching links between ammonia and other nitrogen compounds in the environment. He coordinated the LANAS (Landscape Analysis of Nitrogen and Abatement Strategies) project of the NERC GANE programme and coordinated the NitroEurope Integrated Project, 2006-2011 (€28M, 64 partner institutes) addressing the net effect of nitrogen on the European greenhouse gas balance. In developing the European platform established by NitroEurope, Prof Sutton led the first European Nitrogen Assessment, under the European Science Foundation NinE (Nitrogen in Europe). He was also lead on the Global Overview on Nutrient Management for UNEP 'Our Nutrient World' (2013) and is spearheading the 'International Nitrogen Management System' as a developing mechanism of science support for the emerging 'nitrogen policy arena'.

Presentation Summary: The nitrogen we breathe (N_2) forms 78 % of the atmosphere. In its more reactive forms (e.g. NH_3, NO_x, N_2O), it brings both benefits and risks. It is vitally important to include the public in the nitrogen conversation, outreach via public press is key. We need to be able to understand the processes better and translate this information across to the general public. Carbon footprints and greenhouse gases often get a lot of publicity, yet issues relating to nitrogen pollution are seldom published. Nitrogen pollution is a key source of many environmental problems. The conversion of N_2 into NH_3 using the Haber – Bosch process was potentially the greatest invention of the 20th century. Its production has had a significant impact on the world, 48% of today's population exist due to the increased production based on nitrogenous fertilisers. This increase in the human population coincides with a comparable increase in livestock numbers. While it may be argued that nitrogenous fertilisers are necessary for food security, in reality 80 % of the harvested nitrogen in the world goes to feed/maintain livestock. Europe in particular has more livestock than is necessary for a healthy diet, it seems to be the case that nitrogen is necessary for feed security rather than food security.

There needs to be an effort made to start thinking about, and talking about nitrogen in a joined up fashion. Unless the public get involved, following public outreach, nothing will happen at either a governmental or NGO level. The European Nitrogen Assessment started with 21 reasons to care about nitrogen, which was later reduced to 9 reasons to care about nitrogen / 9 threats from nitrogen. The acronym WAGES is used to cover the multiple reasons to be concerned about nitrogen and its impacts, namely: **W**ater quality, **A**ir Quality, **G**reenhouse gases, **E**cosystems and **S**oils. Maps have been generated showing on a broad scale, the nitrogen concentration and deposition across Europe. Given Ireland's wet climate, enhanced wet deposition and leaching could be potentially more problematic than across Europe.

There are multiple measures that could be implemented in order to see improvements in nitrogen management, many of which may also including saving money: for example, more efficient fertilisers, better livestock, better manure management, better water retrieval, and promoting diets with less meat. Considering 85% of nitrogen is going to feed livestock, only 15% is going to feed people. People are currently eating 70% more protein than is required as part of a healthy diet, there is huge opportunity for social discussion about food choice. The five most effective measures to reduce NH_3 emissions for example are lower emission landspreading, improved feeding strategies, covers on new stores, farm nitrogen balances and additional measures taken on new animal houses. If the population were to halve their meat consumption, associated pollution would decrease by 40 %. This has coined the term "demitarian", where someone makes a conscious decision to halve meat consumption primarily for environmental reasons.

Translating the impacts into costs may be a useful method for encouraging public participation and governmental action. Rather than just saying measures could be put in place to save the EU 15 billion a year, translating it to percentage of the total EU agricultural budget may be more effective. In this case it accounts for 25 % of the total EU agricultural budget.

Prof. Mark Sutton gives his keynote address "Atmospheric Nitrogen Pollution: Sources, Impacts & Solutions".

Dr. Gary Lanigan – Teagasc

Dr. Lanigan is an experienced gaseous emissions research officer from Teagasc Ireland. He is primarily focused on quantifying and drawing up mitigation strategies for gaseous emissions associated with agricultural practices. These emissions include the major greenhouse gases; carbon dioxide, methane and nitrous oxide, as well as non-greenhouse emissions, such as ammonia.

In particular, he is interested in looking at the effects of changes in land management and/or land use on nitrous oxide, carbon and ammonia fluxes. Examples of his current work include; an evaluation of strategies to control ammonia emissions from the land spreading of cattle slurry and cattle wintering facilities and managing soil organic carbon in Irish agricultural soils.

Presentation Summary: Across Europe, agriculture generally contributes 10% of all greenhouse gas emissions. Ireland's agricultural emissions exceed 30% of total greenhouse gas emissions. This is due primarily to a large livestock dominated agri sector, and a very small heavy industry sector. Similar to the rest of Europe, 98% of ammonia emissions arise from agriculture in Ireland. Approximately 80% of this is directly attributable to the bovine sector, i.e. beef and dairy. The remainder is due to emissions from a combination of pigs, poultry, horses, mink, sheep, etc.

The Irish bovine sector is pasture based, hence animals spend roughly nine months of the year on grass, and the remainder of the year housed. Methane (CH_4) produced by grazing animals is particularly problematic, in addition to N_2O produced from urination and defecation in the field. Emissions become concentrated during the housing season, where ammonia emissions also become an issue. The slurry produced is generally landspread, leading to further NH_3 and NO_x emissions.

Prior to the Common Agricultural Policy (CAP), emissions were higher due to higher sheep populations; following the introduction of CAP. emissions decreased with a small decrease in the beef herd. Emissions are currently increasing, primarily due to the removal of the dairy quota.

Government production policy is only one part of the picture. Other national and international policies such as the EU 2020 Climate and Energy Package need to also be considered. This sets a 20% reduction target for Ireland, following which a 30% reduction is required by 2030 under the Climate and Energy Framework. Current predictions suggest that by 2030, GHG emission will be 6% higher than 2005 levels, rather than the target of 30% under 2005 levels. Ammonia emissions will be c. 7% higher, rather than 5% lower. In order to offset the increased production, a decrease in emissions of 12% will be required rather than the 5%. Ireland needs mitigation for both greenhouse gases and ammonia. Alternatives to standard splash plate spreading are vital mitigation measures; nitrogen loss through the atmosphere when using a splashplate can be c. 30%, but when spread on hot days can reach 90%. Altering the spreading methodology not only reduces emissions but also reduces the loss of valuable nitrogen for the farmer.

Other mitigation measures can include reducing dietary nitrogen (less protein in feed means lower nitrogenous emissions), inclusion of clover in the grass sward, spreading or feeding the cattle supplements, e.g dicyandiamide (DCD), adding acidifiers to slurry, etc. In general, the adoption of new technologies will see costs reduce over time.

Ireland needs to apply these measures and mitigate impacts associated with Food Wise 2025. It is important that greenhouse gas inventories are refined, and most suitable methods for different conditions and soils are applied. It is possible that Ireland could meet the 2030 targets if implemented correctly. Farmers are predominantly on board to adopt these measures. The importance of outreach is highlighted to encourage awareness of the problems, solutions and to be part of the solution.

From left to right - David Dodd (Department of Communications, Climate Action and Environment), David Kelleghan (University College Dublin), Dr. Gary Lanigan (Teagasc), Prof. Mark Sutton (Centre of Ecology and Hydrology).

Early Career Researchers (In order of appearance)

Brian Doyle – PhD Student DkIT

Brian is a PhD student PhD with the Marine Institute and Dundalk Institute of Technology. He is presenting work from his research masters based in University College Dublin which carried out a national ammonia monitoring program in collaboration with Trent University. His presentation is entitled 'The spatial and temporal variation of ambient atmospheric ammonia in Ireland'.

Presentation Summary: Ammonia (NH_3) is a highly reactive and soluble alkaline gas, originating from both natural and anthropogenic sources, the primary source of which in the atmosphere is agriculture, e.g. manures, slurries and fertiliser application. Excess nitrogen can cause eutrophication and acidification effects on semi-natural ecosystems, which in turn can lead to species composition changes and other deleterious effects. Emissions and deposition vary spatially, with "emission hot-spots" associated with high-density intensive farming practices. Other agriculture-related emissions of ammonia include biomass burning or fertiliser manufacture. Ammonia is also emitted in small relative proportions from a range of non-agricultural sources, i.e. catalytic converters in petrol cars, landfill sites, sewage works, composting of organic materials, combustion, industry, wild mammals and birds, etc. In general, 44% of ammonia is dry deposited onto foliar surfaces, whereas 6% will be wet deposited. The remaining 50 % will be converted to ammonium of which 36 % is wet deposited and 14% dry deposited. From a human health perspective, as an alkaline gas ammonia reacts with acids in the atmosphere to form salts such as ammonium bisulphate and ammonium nitrate which contribute to PM which has been linked to impacts on human health.

In 2015, the Ammonia2 project in UCD monitored a network of 25 ammonia monitoring stations using Willems badges. There was increased concentrations of ammonia in the East of the country, similar to trends seen in a similar project carried out in 1999. The Willems badges were exposed in triplicate at each site for two week periods, following which they were posted to Trent University in Canada for analysis. This research shows the spatial variation of ammonia across Ireland, with concentrations primarily associated with agricultural activity. The average concentration at all sites for the year of monitoring was 1.72 $\mu g/m^3$. The lowest reading was taken from Mace head at 0.48 $\mu g/m^3$, the highest measurement taken in Cavan of 2.96 $\mu g/m^3$. As monitoring was carried out remotely from intensive agriculture, it is likely that concentrations near intensive farming units are significantly higher than those monitored as part of the Ammonia2 project. Deposition maps were created using aerial concentrations of ammonia and Corine land cover mapping and Met Éireann rainfall data.

In conclusion, sensitive eco-systems within areas of high concentrations are under threat, the project confirms the need for a permanent monitoring network, which would help ascertain trends associated with programmes such as Food Wise 2025.

David Kelleghan – PhD Student UCD

David is a PhD student within UCD School of Biosystems and Food Engineering. Originally an ecologist and geospatial analyst, he is applying his skills to better understand the potential scale of impact from intensive pig and poultry farming in Ireland on the Natura 2000 network of designated sites. His project is entitled "Assessment of the impact of ammonia emissions from intensive agricultural installations on SPAs and SACs".

Presentation Summary: The focus of his project is to quantify emissions from 4 case study pig and poultry farms, in addition to assessing the environmental impact of ammonia emissions from pig and poultry farms on Natura 2000 sites in Ireland. This will contribute to the licensing of installations, Appropriate Assessments, PRTR reporting, and should also assist with assessment of developments under Food Wise 2025. Onsite, the study is monitoring ammonia (NH_3) concentrations within the pig and poultry houses using Cavity Ringdown spectroscopy, in addition to carbon dioxide (CO_2) readings using a Senseair K30 sensor. On average, the emission factors observed in broiler and layer houses are closer to the figures used in the UK SCAIL project, rather than current Environmental Protection Agency (EPA) emission factors.

Monitoring on the pig farms will cover 3 No. dry sow houses, 4 No. fattening houses, 3 No. stage 1, 3 No. stage 2, and 3 No. farrowing houses. This will allow for the development of a suite of emission factors which will give a range of emissions for the entire life span of the pigs. Though emissions are relatively low for pigs and poultry on a national scale, due to the intensive nature of their farming, the concentrations can potentially exceed critical levels and loads for atmospheric nitrogen nearby.

Based on training received in the Centre of Ecology and Hydrology (CEH), the AmmoniaN2K project will be carrying out passive ammonia sampling on Natura 2000 sites on behalf of the National Parks and Wildlife Service. The sampling sites are based on Conservation Ranger availability. CEH ALPHA samplers will be posted to the Conservation Rangers who will deploy them once every 30 days. This will give the NPWS an indication of actual ammonia concentrations present on a small selection of sensitive sites.

The AmmoniaN2K project is also producing a qualitative model to predict Natura 2000 sites which are at risk of impacts from atmospheric ammonia. Using data obtained from CEDaR in Northern Ireland, a map of 32,000 nitrogen tolerant and sensitive lichen species has been created. Reclassifying this data on a scale from 0 – 5 allows for normalisation between multiple datasets, where 5 is the most likely to be representative of an impact and 0 being the lowest. By integrating the locations of intensive units, with cattle population data and NH_3 monitoring, it is possible to identify areas that are potentially at high risk, based on both ecological and farm data. Under Article 9 of the new National Emissions Ceilings Directive, which requires a risk based approach to ammonia monitoring on sensitive sites. This method may be suitable in deciding which sites would be most appropriate for monitoring under the EU Directive. Discussion following the presentation suggested that weighting model components by emissions per potentially impacted area may be more realistic than using arbitrary equal weights for each model component.

Antonio Cachinero Vivar – Forest Engineer UCD

Antonio is a Forest Engineer within UCD Agriculture & Food Science specialising in environmental monitoring. He is currently conducting research within CForRep, ForSite & ShortFor projects. In parallel, Antonio develops prototype sensors focused on research purposes. His most recent approach could be used as part of a national monitoring programme and in potential collaboration with projects such as iSCAPE. His presentation is entitled "Development and evaluation of a portable monitoring unit (PMU) for measuring air quality conditions at the lower troposphere".

Presentation Summary: Real time monitoring of air pollution such as ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ammonia (NH_3) provides information on their direct impact on human and ecosystem health. However, there are limited observations owing to the cost and expertise required to establish permanent continuous monitoring stations. The availability of low-cost microprocessors and sensors provide the possibility of developing a less-costly unit designed for flexible deployment in several locations. These could take detailed measurements over a shorter period of time, compared to long term stationary sensors. Furthermore, adding a dust particulate matter sensor, the unit will extend its range to urban areas.

The main objective of this work is to develop and assess an all-inclusive low-cost device for field measurements being able to provide either real time display, logging or wireless data transfer based on C++ & PHP languages.

The electromechanical sensors used for this purpose are low-power, consistent and low-cost, and are based on expanded understood sensor methodologies debugged for sensing chosen atmospheric gases at the ppb levels in the lower troposphere.

This monitoring data will allow us to assess how air pollution is fluctuating day to day over Ireland at any remote location, determining which regions are the most affected and how levels are behaving so that we can predict which weather conditions will produce pollution episodes, after analysing meteorology and air quality relationships.

Dr. Jim Johnson – Post Doctoral Research Fellow UCD

Jim is a Postdoctoral Research Fellow in UCD School of Agriculture & Food Science. He is interested in human influence on the biogeochemistry of forest ecosystems particularly the effects of atmospheric deposition and harvest intensity on the cycling of nutrients such as nitrogen, potassium, phosphorous. Nitrogen is a limiting nutrient in forest ecosystems and as such is tightly cycled. However, the deposition of bioavailable nitrogen has increased threefold since the mid-nineteenth century leading to a number of ecological impacts including changes to plant community composition, tree growth and nutrition as well as nitrogen cycling processes. In his presentation he will use monitoring data from an oak woodland in the west of Ireland to assess its nitrogen status, potential impacts and future outlook. His presentation is entitled "Monitoring of nitrogen deposition effects at Brackloon, a maritime oak woodland".

Presentation Summary: Atmospheric deposition of inorganic nitrogen (N) has the potential to alter N cycling in a number of ways including: altered growth in the trees, changes in ground vegetation, imbalances in tree nutrition, soil acidification and nitrate leaching. Long-term monitoring of forest health and biogeochemistry takes place at three forest plots around the country: Roundwood, Dooary and Brackloon. The primary reason for monitoring is to understand the cause and effect relationships between atmospheric deposition and impacts, while also monitoring changes in sensitive ecosystems. This supports emissions control protocols, e.g. the UN Convention on Transboundary Air Pollution and the EU National Emission's Ceiling Directive. The first sampling was carried out in Brackloon 25 years ago, with observations continuing to the present day. Over that time period, deposition of oxidised and reduced N in rainfall has decreased. In throughfall, nitrate has decreased but ammonium deposition has remained unchanged. The forest stand shows no signs of excessive N inputs; foliar N, soil solution nitrate and soil C:N ratios all indicate strong N limitation. In conclusion this type of long term monitoring is very beneficial for tracking changes on sensitive ecosystems, which is of particular importance considering the requirements for monitoring under the new National Emissions Ceilings Directive.

Aneesh Kale – Research Masters UCD / Teagasc

Aneesh is a research masters student co-supervised by staff in UCD and Teagasc. His project will review available modelling studies which look to estimate nitrogen emissions from livestock systems and evaluate the cost effectiveness of ammonia mitigation strategies at a farm level in Ireland. His presentation is entitled "Modelling ammonia emissions from pasture based livestock systems."

Presentation Summary: Nitrogen is lost as ammonia (NH_3) at many stages in livestock rearing from housing to storage to spreading, etc. It needs to be modelled in order to give us a better understanding of how to minimise its potential impacts and also reduce the loss of the valuable nutrient required as manure. Individual studies of this nature are expensive and time consuming, and few existing studies look at the entire process at farm level. This project is conducting an extensive literature review of nitrogen flow models, and assessing their suitability for pasture based systems. It will also conduct an evaluation of NH_3 abatement strategies and their cost effectiveness. In total, 27 studies and models have been assessed thus far. While some models solely looked at greenhouse gases, some investigated all nitrogen losses and flows, with others looking at samples of either nitrogen losses and/or flows. This work aims to show whether these models are suitable for Irish pasture based systems, or if a new nitrogen flow model needs to be generated.

Stuart Kirwan – PhD Student UCD

Stuart is currently working as part of the broader "Low Ammo Project", the focus of which is the "Measurement and abatement of ammonia emissions from agriculture". The project is funded by the Department of Agriculture, Food and the Marine. Stuart's work is currently focused on the "Mitigation of Ammonia Emissions: Dietary Strategies", with Dr. Karina Pierce and Associate Professor Tommy Boland in UCD. The objectives are to: 1) Investigate the use of low protein diets, forage source and ratio and the use of by-products for beef cattle as a means of reducing N excretion and altering the N excretion pathway from urinary to faecal N; 2) Investigate by-product feeding and novel dietary supplements to reduce N excretion and alter the N excretion pathway from urinary to faecal N using the RUSITEC artificial rumen system.

Presentation Summary: Under targets set by the Department of Agriculture, Food and Marine in Food Harvest 2020 an expected increase of 50% in milk production from the dairy sector in addition to 20% added output value for sheep and beef can be expected. This increase in production is in conflict with targets to reduce greenhouse gases. Irish agriculture contributes 98% of total NH_3 emissions, with the cattle sector contributing 72% of the total emissions. Nitrogen (N) efficiency in ruminants is very low with 25-34% and 10 - 20% of total nitrogen ingested retained in dairy cows and beef cattle respectively.

In Ireland, beef cattle spend 8-9 months grazing pasture with the remaining 3-4 months housed and fed a conserved forage, predominantly grass silage. With this feed, the main carbohydrate substrates available for fermentation in the rumen are slowly fermented plant cell walls. The nitrogen substrates in grass silage are mainly soluble or very quickly available. This asynchronous release of energy and N components in the rumen has often been considered an important cause of the low efficiency of microbial growth observed with diets such as grass silage. The objective of our first study is to evaluate the effect of alternative energy sources with different fermentation profiles on nitrogen metabolism of beef heifers offered grass silage. Dietary treatments were as follows: grass silage plus rolled barley (RB), grass silage plus maize meal (MM) and grass silage plus soya hulls (SH) based concentrate. From the results, there was a time by treatment interaction for rumen NH_3 concentrations. At 1 hr post feeding MM supplemented animals had higher rumen concentrations than RB supplemented animals, but this response was reversed at 4 and 6 hrs post feeding, while at 6 hrs post feeding NH_3 concentrations for the RB supplemented animals was higher than SH supplemented animals. Independent of treatment, rumen pH increased over time post feeding. The second study will investigate the effects of feeding chitosan differing in molecular weight on rumen fermentation in vitro using the artificial Rumen Simulation Technique (RUSITEC). Chitosan is formed from the deacetylation of chitin, a biopolymer found in the exoskeleton of insects and crustaceans and also present in fungi. Chitosan has many possible applications in food preservation, pharma industry, human and veterinary medicine due to its antimicrobial properties. It is expected that supplementation with chitosan, low in molecular weight will have an impact on rumen fermentation.

Conor Bracken –PhD Student UCD

Conor is a PhD student co-supervised by staff in UCD, Teagasc, and Justus Liebig University in Germany. His project aims to develop and validate a method for measuring nitrous oxide (N_2O) using Cavity Ring Down Spectroscopy. The new method will be used to study the effects of mixed species grasslands on N_2O emissions from Irish soils. His presentation was entitled **"**Investigating the impact of nitrogen source and management on nitrogen cycling and nitrous oxide emission from agricultural soils using Cavity Ring-Down Spectroscopy (CSDS)".

Presentation Summary: Above ground communities will impact on below ground microbiome. It is therefore of interest to study the effect of multispecies swards on N_2O emissions from soil. CRDS is a new measurement technique for stable isotope research. The aim of this work is to establish and validate a standard operating procedure for N_2O measurement using CRDS. In addition, CRDS will be used to investigate the effect of above ground plant community structure on N_2O source in Irish soils.

N_2O comes from a number of sources in soil such as nitrification / denitrification controlled by different organisms (bacteria or fungi). Depending on the enzymes these organisms use during metabolism this will affect the end product of the reactions taking place. Stable isotopes have been applied as a tool to investigate how these reactions proceed which is particularly of importance when N_2O is the end product.

Stable isotopes are a useful research tool, due to the fact that heavier isotopes require more energy to be used in chemical reactions, 15N is a natural tracer of how N is moving in an agricultural system. Applying N_2O isotopomers as a research tool in the past has shown that they can be used as indicators of the different soil processes that are causing N_2O loss from soil. This is very helpful for testing N_2O mitigation strategies in agriculture. These and most other previous studies were carried out using gas chromatography (GC) and isotope-ratio mass spectrometry (MS) methodologies.

Laser based spectroscopy techniques such as TDL (tunable diode lasers), QCLAS (quantum cascade laser absorption spectroscopy) and CRDS (cavity ring down spectroscopy) have recently emerged as an alternative to GC and MS for measuring N_2O concentration, isotope ratio and isotopomers. Laser based measurements promise to provide more information with greater resolution data. An important part of the project is to initially establish a Standard Operating Procedure for measuring N_2O samples using CRDS and to validate this new method.

Ian Kavanagh – Research Masters NUIG / Teagasc

Ian is a research masters student co-supervised by staff in the National University of Ireland Galway and Teagasc. His research looks at mitigation techniques to reduce ammonia emissions from cattle slurry, using different acidifiers and chemical amendments. His presentation is entitled "Mitigating ammonia emissions from slurry storage".

Presentation Summary: 98% of ammonia emissions arise from agriculture, cattle account for 80% of Ireland's agricultural ammonia (NH_3) emissions, of which manure storage contributes 15% (important for this project). Ireland must reduce emissions by 10% by 2025; the majority of Irish ammonia research has focused on manure land spreading, artificial fertilizers and formulations. The objective of this work is to quantify the abatement potential of slurry treatment and housing strategies for reducing losses of NH_3 from slurry during storage. This study is investigating four main amendments to be included in slurry and their effects investigated, these amendments are chemical, chemical alternatives, commercial, and engineering.

The chemical amendments primarily include additions of alum, ferric chloride, acetic acid and sulphuric acid. Results showed significant reduction of ammonia for all the chemical amendments. Acetic acid in particular showed a 74% reduction of ammonia. In addition, chemical amendments showed c. 90% reduction in methane emissions. Interestingly, ferric chloride showed a 98% reduction in methane emissions.

Alternatives to chemical amendments will investigate the effectiveness of reducing ammonia emissions using cheap acidifiers. Amendments chosen for inclusion are: apple pulp, sugar beet molasses, spent brewers grain, dairy waste, silage effluent, maize effluent, and whiskey by-product. These alternatives are cost free, except for the molasses.

Commercial products will also be investigated, many of these are already available on the market but have little or no scientific evidence to back them up. A pilot facility has been set up by Teagasc; this will be used to simulate winter storage conditions which will allow for accurate comparisons of mitigation techniques.

Workshop Conclusions

Ireland is already carrying out small scale monitoring of ammonia emissions and concentrations. This monitoring needs to be expanded and made long term. In addition to ammonia monitoring, ammonium aerosol monitoring should also be expanded. In Northern Ireland, both are being monitored, a key finding from which is that over time ammonium aerosol is decreasing quicker than atmospheric ammonia concentrations. A similar scenario seen in the Netherlands was due to less acidic compounds in the atmosphere, which maintains the higher levels of ammonia gas. Monitoring both ammonia and ammonium was vital for effective policy in the Netherlands in this case. In addition, work is required on the little discussed “amines”, and their associated impacts.

Given the sensitivity of special areas of conservation (SAC) in Ireland and the high level of agricultural productivity, there is a need to assess the potential impacts of ammonia on SACs both north and south of the border. The AmmoniaN2K’s qualitative risk assessment procedure could be extended to fit Northern Irish data relatively easily, from which the SACs most at risk would be easily identifiable.

A risk based approach to the new ecosystem monitoring requirements in the NECD (Article 9 Annex 5) is required. Also, grant aided technical measures for ammonia abatement (e.g. low emission slurry spreading) need to be made available to contractors as well as the general farming community so that higher levels of ammonia abatement can be achieved. It is also necessary to look at other infrastructural measures as well such as slurry cover/stores.

A National Code for Good Agricultural Practice for Reducing Ammonia Emissions needs to be prepared within 12 months of Ireland ratifying the Gothenburg Protocol under the Convention on Long Range Transboundary Air Pollution. The protocol is due to be ratified by the end of 2017. Much of the research work being undertaken nationally, some of which was discussed at the workshop will be of benefit in developing this new code of practice.

A detailed discussion on nitrogen budgets is required, followed by a detailed nitrogen budget which can be updated regularly to provide a driver for policy, allowing for substantial savings to be made. Both farm level margin budgeting and also national level budgeting needs to be considered. There is a need to unify all data into one single inventory so that there is no discrepancy between what is in the Nitrates Directive, what is in the ammonia inventories, and what is in the greenhouse gas inventories. Work being carried out under the MapEire project in the University of Aarhus aims at producing national maps of emission sources for pollutants including ammonia.

Research is required to investigating soil NO_x emissions, in order to adequately apportion sources of impacts to both agricultural and natural sources. Joined up thinking is required in the future. It may be the case that Ireland has a high fraction of its NOx emissions from agricultural soils. This is an area which could be problematic in the future.

Future Research Needs

This workshop gave an excellent overview of some of the research being conducted in Ireland, highlighting areas that require additional research. Based on the discussion on the day, the following areas have been identified as requiring further work:

- Continuous monitoring of both ammonia gas and ammonium particles is urgently required, and existing monitoring needs to be significantly enhanced.
- The potential impact of amines, which in addition to further research may require additional national monitoring. As amines are derived from ammonia, it would be important to quantify and consider their impact in addition to ammonia concentration and ammonium deposition.
- A risk assessment of atmospheric ammonia on Natura sites is urgently required to comply with the new National Emissions Ceilings Directive.
- Modelling potential risk areas should be based on contribution to total emissions per area potentially impacted.
- Following the identification of at risk Natura 2000 sites, the monitoring of atmospheric ammonia being conducted by AmmoniaN2K on Natura 2000 sites needs to be expanded.
- The CEDaR lichen database should incorporate TELLUS lichen records, which could be used to assess potential impacts from total nitrogen impacts rather than merely incorporating it into an ammonia risk assessment.
- Work needs to continue researching nitrogen budgets, focusing on both farm and national levels. Work being carried out by MapEire in Denmark may provide a first step in developing a detailed national geospatial nitrogen budget.
- Once a detailed emission map is produced, a cumulative impact assessment of all sources of ammonia needs to be carried out on the Natura 2000 network.
- Further research is required to quantify the contribution of Irish soils to NOx emissions, in particular the diversity of agricultural soils will need to be assessed.
- Existing research needs to be assessed and integrated with the development of a National Code for Good Agricultural Practice for Reducing Ammonia Emissions.