EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

THEO MURPHY INTERNATIONAL SCIENTIFIC MEETING ON

Nitrous oxide, the forgotten greenhouse gas

Monday 23 – Tuesday 24 May 2011
The Kavli Royal Society International Centre

Organised by Professor David Richardson, Professor Andrew Watson FRS, Professor Andrew Thomson OBE FRS and Professor Jules Pretty OBE

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Synopsis
Many soil bacterial use nitrate to support respiration, especially after application of nitrogen fertilizer, leading to production of the potent and long lived greenhouse gas nitrous oxide (N2O). This meeting will review our current understanding of the enzymatic and bacterial processes by which N2O can be produced or destroyed and discuss approaches for combating N2O release.

Monday 23 May 2011

9.00 Welcome by Professor David Richardson, Organiser

Session 1: Biological sources of N2O emissions and consequent problems
Chair – Professor David Richardson, University of East Anglia, UK

9.30 The role of N2O derived from biofuels in earth's climate
Professor Paul Crutzen, Max Planck Institute for Chemistry, Mainz, Germany

The relationship, on a global basis, between the amount of N fixed by chemical, biological or atmospheric processes entering the terrestrial biosphere, and the total emission of nitrous oxide (N2O), has been re-examined, using known global atmospheric removal rates and concentration growth of N2O as a proxy for overall emissions. Taking into account the large-scale changes in synthetic N fertiliser production, we find an overall conversion factor of 3–5% for newly fixed N to N2O-N. When the extra N2O emission from biofuel production is calculated in "CO2-equivalent" global warming terms, and compared with the quasi-cooling effect of "saving" emissions of fossil fuel derived CO2, the outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), depending on N fertilizer uptake efficiency by the plants, can contribute as much or more to global warming than cooling by fossil fuel savings.

10.00 Discussion

10.15 Ozone depletion due to nitrous oxide
Professor Robert Portmann, NOAA Earth Systems Research Laboratory, Boulder CO USA

The chemistry controlling ozone levels in the stratosphere and its natural balance are summarized. Nitrous Oxide (N_2O) is converted to nitrogen radicals in the stratosphere. Research in the 1970's recognized these nitrogen radicals play a key role in maintaining the natural level of ozone. Since anthropogenic emissions of N_2O are significant they also affect the ozone balance. In addition, it is well recognized that halogenated compounds have had a very large impact on ozone since the 1970's.

The long-term evolution of ozone deduced from observations is discussed. A model is used to separate the effect of N_2O and other ozone depleting substances (ODSs) and compare with the observations. Pitfalls in separating N_2O's effects using recently proposed regression techniques are exposed. Ozone depletion potentials (ODPs) quantify the long-term effect of emissions of ODSs on ozone and allow the emissions of different classes of compounds to be compared. We use the ODP of N_2O to compare its ODP-weighted emissions with other ODSs. This shows that anthropogenic N_2O is the largest destroyer of stratospheric ozone being emitted in recent years and is likely to remain so in the future.

10.45 Discussion

11.00 Coffee

11.30 Nitrous oxide emissions from wastewater treatment systems
Professor Zhiguo Yuan, The University of Queensland, Australia

Biological nitrogen removal (BNR) from wastewater is achieved through nitrification and denitrification. Both processes are potential sources of nitrous oxide (N_2O), contributing to the carbon footprint of a wastewater treatment system. N_2O production during wastewater treatment has attracted considerable research in the past decade, and in the last few years in particular. Research has focused on not only the quantification of emissions but also the mechanisms involved in N_2O production. On average, approximately 1% of the total amount of nitrogen removed in a BNR plant is emitted as N_2O, adding significantly to the total greenhouse gas emissions from wastewater systems. However, this emission factor varies substantially across plants. In some cases, N_2O emission has been found to dominate the total carbon footprint of the treatment plant. In addition, N_2O production has also been found to be highly dynamic, varying rapidly, likely caused by the variations in operational conditions and wastewater characteristics. Many factors have been revealed to have significant influences on N_2O production by both nitrification and denitrification. These included pH, dissolved oxygen, free nitrous acid, carbon supply and transition between anoxic and aerobic conditions. These findings indicate that N_2O emissions from BNR plants may be mitigated by applying operational conditions that reduce N_2O production. However, few studies have been reported to date focusing on the mitigation of N_2O production and emissions in BNR plants. In this paper, research on N_2O production and emissions in wastewater systems is critically reviewed, with the results compared with those obtained in other systems. Future research questions are identified.

12.00 Discussion

12.30 Lunch

Session 2: Biological production and consumption of nitrous oxide
Chair - Professor Stephen Spiro, University of Texas at Dallas, USA

13.20 Control of N2O production and consumption: regulation of gene expression by gas-sensitive transcription factors
Professor Stephen Spiro, University of Texas at Dallas, USA

Amongst the major sources and sinks for N2O are the respiratory nitric oxide (NO) and N2O reductases, respectively. Hence, a major component of the control exerted on N2O production and consumption is the regulation of transcription of the NO reductase (nor) and N2O reductase (nos) genes. Typically, the nor genes are coordinately regulated with the nir gene encoding the nitrite reductase, as a means of minimizing the accumulation of NO. Regulation of nos gene expression is not well understood, but apparently does not involve induction by N2O. Since nor and nos gene expression is not tightly coupled, the potential exists for N2O to 'leak' from the denitrification pathway, and denitrification is indeed a significant source of N2O. In this presentation, I will review our current understanding of the genetic requirements for the synthesis of active NO and N2O reductases, with a particular focus on the structure and function of the regulatory proteins that influence nor and nos gene expression. Expression is typically influenced by regulatory systems that respond to oxygen and NO; other important signal inputs include nitrate, and the redox state of the electron transport chain. There turns out to be a surprising degree of diversity in the organization of the regulatory networks that control denitrification in different bacteria.

13.50 Structural basis for nitrous oxide generation by bacterial nitric oxide reductases
Professor Yoshi Shiro, RIKEN SPring-8 Center, Japan

Bacterial nitric oxide reductase NOR is a membrane-integrated and iron-containing enzyme, which is involved in denitrification, a kind of anaerobic respiration. Since NO generated in the denitrification process exhibits a high cyto-toxicity, NOR immediately decomposes NO into nitrous oxide N2O, according to the following scheme; 2NO + 2H+ + 2e- → N2O + H2O. Since the largest part of the N2O emission on the earth is caused by this reaction, NOR is now realized as a main player of the ozone layer depletion. We succeeded in structural determination of cytchrome c dependent NOR (cNOR) from Pseudomonas aeruginosa and quinole-dependent NOR (qNOR) from Geobacillus stearothermophilus. They have a catalytic active center consisting of heme and non-heme iron, which is located in trans-membrane helices. On the basis of their molecular structures, we can discuss the molecular mechanism of their enzymatic reactions; NO binding, proton and electron transfers. Especially, molecular dynamic simulation provides a great insight into the proton/water transfer from either outside or inside of the cell to the active site. In addition, we can compare their structures with those of cytochrome oxidases in aerobic and micro-aerobic respiration to examine the molecular evolution of the respiratory enzymes, since NOR is classified into the heme-copper oxidase superfamily.

14.20 Discussion

14.35 Enzymology breaking down nitrous oxide- the nitrous oxide reductase
Professor Isabel Moura, Universidade Nova de Lisboa, Portugal

The final step of bacterial denitrification, the two electron reduction of N2O to N2 is catalyzed by a multicopper enzyme named nitrous oxide reductase. The catalytic center of this enzyme is a tetranuclear copper site called CuZ unique in biological systems.

The structure of CuZ center opened a novel area of research in metallobiochemistry. In the last decade, there has been progress in defining the structure of the CuZ center, characterizing the mechanism of nitrous oxide reduction, and identifying intermediates of this reaction.

The crystal structure of N2OR from Pseudomonas nautica was solved to a resolution of 2.4 Å. This enzyme contains one binuclear (CuA) and a tetranuclear copper center (CuZ), an unusual structure (catalytic site). CuZ center is a new type of cluster, in which four copper ions are coordinated by seven histidine residues. In addition, the determination of the structure of the CuZ center allowed a structural interpretation of the spectroscopic data, which was supported by theoretical calculations. The current knowledge of the structure, function, and spectroscopic characterization of the nitrous oxide reductase will be addressed in this talk. Although many questions have been answered about this enzyme it remains a scientific challenge, with many hypotheses being formed.

15.05 Discussion

15.20 Tea

15.40 Nitric oxide reductase cytochrome P450nor involved in fungal denitrification to evolve N2O

Professor Hirofumi Shoun, The University of Tokyo, Japan

The fungal denitrifying system comprises the minimal couple, NirK (copper-containing nitrite reductase) and P450nor (nitric oxide reductase). Some fungi (Fusarium oxysporum) also contain nitrate reductase that resembles bacterial Nar GHI. The fungal system was shown to function as mitochondrial anaerobic respiration. Fungal denitrification is often accompanied by a unique phenomenon, codenitrification, which is the first to show that a hybrid N2 or N2O species is formed upon combination of nitrogen atoms from nitrite and other nitrogen compounds. P450nor belongs to the cytochrome P450 superfamily, but its function (2NO+NADH+H+→N2O+H2O) is quite unique as compared with other monooxygenase P450s. During the catalytic cycle, ferric (Fe3+) P450nor-NO complex receives a hydride ion (H–) from NADH and a H+ from the proton-donating network, respectively, to form an intermediate with its Soret peak at 444 nm, which should correspond to Fe3+–hydroxylamine radical complex. The conserved Thr residue (Thr243) in the I-helix is not involved in the proton-donating system, but fixes the nicotinamide ring to support the stereochemical H– transfer. A salt bridge network (D88-K64-E71) is important to accomplish the high catalytic number (105 min–1 order). P450nor was also shown to catalyze a codenitrification reaction to form N2O from NO and other nitrogen donors.

16.10 Discussion

17.00 Close

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Session 3: Measuring and modelling N20 balances
Chair – Professor Elizabeth Baggs, University of Aberdeen, UK

9.00 Microbial N2O production in soils: the challenge of scale
Professor Elizabeth Baggs, University of Aberdeen, UK

Scale is a primary consideration when quantifying the soil's contribution to climate change. With better understanding of the controls on N2O production and reduction, it will be possible to develop more targeted mitigation strategies. For this to be effective, we need to bridge the differences in scale considered from soil microbial sources of these gases, the active key microbial groups responsible, interactions between C and N cycles, to vegetation type or plant trait, land-use and even up to national inventories. This remains a challenge. This is in part due to different techniques utilised to quantify processes at different scales. As the scale increases the technique utilised provides a more aggregated response which inherently loses the level of detail provided at the microscale. Here we will consider regulation of N2O production in the rhizosphere, and the challenges we face in bridging our understanding of controls on N2O production from the molecular level, to the rhizosphere, to the field and ultimately to the landscape or regional scale.

9.30 Nitrous oxide in the ocean
Professor Hermann Bange, IFM-GEOMAR, Germany

The global ocean including its coastal areas such as coastal upwelling and estuaries contribute about 30% to the global nitrous oxide (N2O) emissions. Oceanic N2O is produced as an intermediate during microbial denitrification (reduction of NO3– to N2) and as well as a by-product during nitrification (oxidation of NH4+ to NO3–). The amount of oceanic N2O produced during denitrification and nitrification strongly depends on the prevailing oxygen (O2) concentrations. Therefore, increasing nutrient inputs to the ocean, which in turn result in declining O2 concentrations, have been proposed to alter the future oceanic N2O pathways. Additionally, nitrification rates have been shown to decrease significantly when the pH is lowered. Therefore, the ongoing ocean acidification might also affect oceanic N2O production. We do not know, however, to which extent the oceanic N2O pathways will be altered and it is even more difficult to predict how the future oceanic N2O emissions will be affected. Our rather poor ability to predict the future oceanic N2O cycling is due to the fact that we still have an only rudimentary knowledge about both the oceanic distribution of N2O and the mechanisms of its major production processes. Emerging new aspects such as possible N2O formation during anammox (microbial reduction of NO2– with NH4+ to N2) or by nitrifying archeae might have the potential to change our traditional view of the oceanic N2O pathways.

10.00 Discussion

10.15 UK emissions of the greenhouse gas nitrous oxide
Dr Ute Skiba, NERC Centre for Ecology and Hydrology, UK

Soil microorganisms are responsible for over 80% of the global N2O emissions. Emissions are primarily controlled by the availability of nitrogen and organic carbon compounds and the soil's oxygen concentration. Nitrogen fertilised, agricultural soils, dominate N2O inventories in wealthy industrialised nations. For example, in the UK, agricultural soils account for about 75% of annual emissions. Other N2O sources are biomass burning, nylon manufacture and combustion processes. The only N2O sinks are photochemical destruction in the stratosphere, and uptake by soils for denitrification to N2. Agricultural emissions are the most uncertain. To reduce this uncertainty targeted research is currently carried out to provide a better N2O accounting system (IPCC Tier 2 methodology). This will provide different N2O emission factors for dominant crops for a range of soils, climates and agricultural managements. N2O emission rates for new crops, i.e. bioenergy crops and for land use change activities however remain highly uncertain. Agricultural practices indirectly increase N2O emissions from forests, moorlands, riparian zones, estuaries through losses of fertiliser N to the atmosphere and waters. The contribution of these ecosystems to the total UK budget is small, but poorly quantified.

10.45 Discussion

11.00 Coffee

11.30 Nitrous oxide dominates net ecosystem exchange of CO2 equivalents in High Arctic soils under a warming climate.
Dr Steven Siciliano, University of Saskatchewan, Canada

Climate change will have large impacts in the Arctic (1), yet little is known about how the flux of two key greenhouse gasses (GHGs), methane and nitrous oxide, will respond to a warmer climate. We measured net ecosystem fluxes of CO2, CH4 and N2O for two years during the summer from seven different High Arctic tundra ecosystems that had been experimentally warmed (ca. 1-2 °C) for the last 20 years. Experimental warming produced a 10-fold increase in CO2 efflux (from -0.01 to -0.14 µmol m-2 s-1; p=0.037), a four-fold decrease in CH4 influx (from -0.07 to +0.31 nmol m-2 s-1; p=0.053), and had no effect on N2O flux (average influx = 0.32 nmol m-2 s-1; p=0.900). The Arctic soil GHG sink exists due to large, unexpected N2O sinks that remove 0.10 µmol CO2-equivalents m-2 s-1 and methane sinks that remove 0.02 µmol CO2-equivalents m-2 s-1. This is the first report of large N2O sinks in these ecosystems.

12.00 Discussion

12.30 Lunch

Session 4: Strategies for mitigating nitrous oxide emissions
Chair – Professor Jules Pretty OBE, University of Essex, UK

13.20 Agricultural Sustainability: towards low N agriculture
Professor Jules Pretty OBE, University of Essex, UK

All commentators agree that food production will have to increase substantially this century. But there are very different views about how this should best be achieved. Some still say agriculture will have to expand into new lands. Others say food production growth must come through redoubled efforts to repeat the approaches of the Green Revolution, or that agricultural systems should become organic.

Traditionally, agricultural intensification has been defined in three ways: increasing yields per hectare, increasing cropping intensity (i.e. two or more crops) per unit of land or other inputs (water), and changing land-use from low-value crops or commodities to those that receive higher market prices.

It is also now understood that agriculture can negatively affect the environment through overuse of natural resources as inputs or through their use as a sink for pollution. What has also become clear in recent years is that the success of some modern agricultural systems has masked significant negative externalities, with environmental and health problems documented and recently costed for many countries. These environmental costs change conclusions about which agricultural systems are the most efficient, and suggest that alternatives which reduce negative externalities should be sought.

Sustainable intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services (Pretty, 2008; Royal Society, 2009; Conway and Waage, 2010; Godfray et al, 2010; Pretty et al 2011). As both agricultural and environmental outcomes are pre-eminent under sustainable intensification, such sustainable agricultural systems cannot be defined by the acceptability of any particular technologies or practices (there are no blueprints). If a technology assists in efficient conversion of solar energy without adverse ecological consequences, then it is likely to contribute to the system's sustainability. Sustainable agricultural systems also contribute to the delivery and maintenance of a range of valued public goods, such as clean water, carbon sequestration, flood protection, groundwater recharge and landscape amenity value. In terms of technologies, therefore, productive and sustainable agricultural systems make the best of both crop varieties and livestock breeds and their agro-ecological and agronomic management.

13.50 Regulation of denitrification at the cellular level – a clue to understand of N_2O emissions from soils

Professor Lars Bakken, Norwegian University of Life Sciences, Norway

Denitrifying prokaryotes (DP) use NO_x as terminal electron acceptors in response to oxygen limitation. The process leads to emissions of NO, N_2O and N_2, depending on the relative activity of the enzymes catalyzing the stepwise reduction of NO_3^- to N_2O and finally N_2O to N_2 (N2OR, N2O-reductase). This is determined by transcriptional control and direction of the electron flow (to O_2 or to NO_x-reductases) in response to environmental variables. We define such response patterns as "Denitrification Regulatory Phenotypes" (DRP), and have found profoundly different DRP both in culture collections and in nature. Studies of DRP help to understand how environmental variables control N_2O-emissions. A common feature of all DRP is that the relative activity of N2OR is correlated with pH (within the range 5-7), apparently due to interference with the assembly of the enzyme. The same phenomenon was demonstrated for soils, and in very acid soils the gene for N2OR appears to be silenced. Liming could be a way to reduce N_2O emissions, but needs verification by measurements of emissions in field experiments. More sophisticated ways to reduce emissions may emerge in the future as we learn more about the regulation of denitrification at the cellular level.

14.20 Discussion

14.35 Using molecular and isotopic tracer studies to elucidate the microbial process controls of nitrous oxide emissions from soils

Professor Keith Goulding, Rothamsted Research, UK

Denitrification in agricultural soils is an important route for loss of fertiliser nitrogen, especially as the greenhouse gas N2O, but the ecology of denitrifier communities, and process controls are not fully understood. In two laboratory experiments we examined the influence on emissions and process controls of (a) different long-term fertilisation and cultivation treatments, and (b) of predicted climate change, modelled as pre-wetted or pre-dried soil. N2O emissions were much higher in soil from woodland than from the same soil growing arable crops and receiving farmyard manure, which in turn was higher than those from inorganic nitrogen-fertilised and unfertilised arable plots. The abundance of bacteria containing nirK best explained the increased emissions, associated with increasing amounts of excess available nitrogen and organic carbon content. Ratios of N2O:N2, measured under closely controlled laboratory conditions, were higher in soils which were pre-incubated under dry conditions than wet, most probably due to the mobilization of organic carbon during the pre-treatment. Time courses of the isotope signatures of 15N2O and 18O2 suggested a non-homogenous distribution of NO3- and denitrification activity in soil. The experiments suggest that predicted climate change impacts of more variable and extreme weather patterns could increase N2O emissions and that managing soil for optimal moisture (via structure), carbon and nitrogen content will be the best way to minimise emissions.

15.05 Discussion

15.20 Tea

15.40 Summary and conclusions

Professor David Fowler CBE FRS, NERC Centre for Ecology and Hydrology, UK

16.10 Panel discussion

17.00 Close

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Organiser, speaker and chair biographies

Dr Elizabeth Baggs, University of Aberdeen, UK (Speaker, Chair)
Liz Baggs holds the Established Chair of soil science at the University of Aberdeen. Her research is focused on greenhouse gas production in soils, developing and applying stable isotope approaches to link process measurements with characterisation of the underpinning microbiology and biochemistry. After her PhD in soil science at the University of Edinburgh, Liz was a Lecturer in soil biology and chemistry at Wye College, University of London, prior to taking up a Wain Research Fellowship at Imperial College London. She moved to Aberdeen on a NERC Advanced Fellowship which ended last year. Her research group is funded by several BBSRC and NERC grants and studentships. She is currently a core member of BBSRC Committee B, a member of the NERC Peer Review College, a steering committee member for the UK Life Sciences Mass Spectrometry Facility, and an Editor for FEMS Microbiology Letters, Soil Biology and Biochemistry and Plant and Soil.

Professor Lars Bakken, Norwegian University of Life Sciences, Norway (Speaker)
Lars Reier Bakken is professor at the Norwegian University of Life Sciences, where he teaches biogeochemistry and microbial ecology. His research covers several aspects of microbial ecology of soils, but has recently concentrated on the ecology and regulatory biology of denitrifying prokaryotes and the implications for production of NO and N2O.

Dr Hermann Bange, IFM-GEOMAR, Germany (Speaker)
Hermann W Bange is a chemist by training and earned his PhD from Mainz University in 1994. From 1995 to 2000 he participated in the German JGOFS Arabian Sea Process Study. Since 2001 he is working as a chemical oceanographer at IFM-GEOMAR in Kiel, Germany. Hermann W. Bange is heading the 'Long-lived Trace Gases' working group of the Marine Biogeochemistry Research Division. Currently he is coordinating the SOPRAN (Surface Ocean Processes in the Anthropocene) project (www.sopran.pangaea.de) which is the German contribution to the international SOLAS (Surface Ocean – Lower Atmosphere Study, www.solas-int.org). Moreover, Hermann Bange is responsible for the activities of the Boknis Eck Time Series Station (SW Baltic Sea, www.ifm-geomar.de/index.php?id=bokniseck) and MEMENTO (The Marine Methane and Nitrous Oxide Database). He is an associated member of the Kiel Cluster of Excellence 'The Future Ocean' and recently he was appointed as SOLAS national co-representative for Germany. His research interests include the oceanic emissions and pathways of trace gases such as nitrous oxide, methane and dimethyl sulphide. Furthermore, he is interested in the distributions of short-lived intermediates of the marine nitrogen cycle such as hydroxylamine and hydrazine. The activities of the 'Long-lived Trace Gases' working group includes participation in international ship campaigns worldwide and the development of new analytical methods.

Professor Paul Crutzen, Max Planck Institute for Chemistry, Germany (Speaker)
Born in 1933 in Amsterdam, Paul J Crutzen was trained as a civil engineer and worked with the Bridge Construction Bureau of the City of Amsterdam. In 1959 he joined Stockholm University (MISU) to study meteorology and atmospheric chemistry. His research has been especially concerned with the natural and anthropogenically disturbed photochemistry of ozone in the stratosphere and troposphere. Thereby he identified the importance of nitrogen oxides emitted by fossil fuel and biomass burning, especially in the tropics, as important sources of air pollution with potential impacts on ozone and Earth climate. He served as Director of Research at the National Center of Atmospheric Research in Boulder, Colorado, 1977-1980, and thereafter – until his retirement - (1980-2000) at the Max Planck Institute for Chemistry in Mainz. Until April

2008 he did part-time research at the University of California, San Diego, Scripps Institution of Oceanography. In 1995 he received the Nobel Prize for Chemistry for his work on atmospheric ozone.

Professor David Fowler CBE FRS, NERC Centre for Ecology & Hydrology, UK (Speaker)
David currently works for the Centre for Ecology & Hydrology (CEH) at their Edinburgh research site near Penicuik, as a Senior Researcher on the sources of atmospheric processing and fate of atmospheric trace gases. David obtained a PhD in Environmental Physics from Nottingham University in 1976 and has worked for CEH since 1975.

David's research career has included work on the major gaseous atmospheric pollutants, aerosols and greenhouse gases with a focus on the processes of surface-atmosphere exchange. He has worked on the long-range transport, deposition and effects of pollutants on vegetation and soil and has been closely involved with assessments of effects of acidification, eutrophication and photochemical oxidants in the UK and the development of policies to address the issues. More recently he has worked on the sources of atmospheric methane and upscaling of fluxes to a regional scale using aircraft. He chairs and sits on several international committees concerned with air pollution within Europe.

David has published over 300 scientific papers and book chapters. He was awarded an honorary professorship from the University of Nottingham in 1990 and elected a Fellow of the Royal Society of Edinburgh in 1999, a Fellow of the Royal Society of London in 2002, and was awarded a CBE in 2005 for services to atmospheric science.

Professor Keith Goulding, Rothamsted Research, UK (Speaker)
Keith joined Rothamsted in 1974 after completing a Masters in Soil Chemistry at Reading University and gained his PhD in soil chemistry at Imperial College in 1980. He studies how the plant foods (nutrients) in soils become available to growing plants and the best ways of augmenting these with fertilisers and manures without polluting air and water; he has engaged in various aspects of the ‘Organic versus Conventional’ farming debate.

He is a visiting Professor at the University of Nottingham, a Fellow of the Institute of Professional Soil Scientists and a Chartered Scientist. He was awarded the Royal Agricultural Society of England’s (RASE) Research Medal in 2003 for his research into diffuse pollution from agriculture and elected an Honorary Fellow of the RASE in 2010. He received a Nobel Peace Prize certificate for his contribution to the work of the Intergovernmental Panel on Climate Change, for which the Panel and Al Gore were jointly awarded the Prize in 2007. He is currently President of the British Society of Soil Science.

Professor Isabel Moura, University of Lisbon, Portugal (Speaker)
Isabel received her Degree in Chemical Engineering from Technical University of Lisbon (Pt) in 1974. She received her Masters in Physical Inorganic Chemistry in 1977 from New University of Lisbon. She was awarded her PHD from New University of Lisbon in 1981 on the thesis entitled “Characterization of two types of iron sulphur centers in two proteins isolated from Desulfovibrio gigas”. Since then she was an Assistant Professor until 1981 in the New University of Lisbon, an Associate Professor in 1986 and a full Professor in 1997. She has done the habilitation in 1994 in the same University.

During her career she was a Visiting Professor in University of Geogia, Athens, USA. During the period 2000/2011 she was the Head of the Chemistry Department of the Faculty of Sciences and Technology from the New University of Lisbon and the Director of the Associated Laboratory Requimte for Sustainable Chemistry. Her main work is Structure-Function of Metalloproteins, application of biochemical and spectroscopic tools (NMR, EPR and Mössbauer), proteins involved in relevant bacterial metabolic pathways – N and S Biocycles.

Professor Robert W Portmann, National Oceanic and Atmospheric Administration, USA (Speaker)
Robert Portmann is a research physicist working at the Chemical Sciences Division at the NOAA Earth Systems Research Laboratory in Boulder, Colorado. He received his PhD from the University of Colorado, studying middle atmospheric climate change. He is a specialist in middle atmospheric modeling with a focus on processes affecting ozone, including the interactions of halogens and greenhouse gases. He has carried out important studies on the ozone hole, ozone trends at mid-latitudes, and the effects of volcanic aerosol on ozone. In addition, he has studied the radiative forcing and global warming potentials of many chemicals proposed as halogen replacements. He was a coauthor on three WMO Scientific Assessments of Ozone Depletion.

Professor Jules Pretty OBE, University of Essex, UK (Speaker, Chair, Organiser)
Jules Pretty is Pro-Vice-Chancellor at the University of Essex, and Professor of Environment and Society. His 18 books include This Luminous Coast (2011), Nature and Culture (2010), The Earth Only Endures (2007), and Agri-Culture (2002). He is a Fellow of the Society of Biology and the Royal Society of Arts, former Deputy-Chair of the government's Advisory Committee on Releases to the Environment, and has served on advisory committees for a number of government departments. He was a member of the Royal Society working group that published Reaping the Benefits (2009) and was a member of the UK government Foresight project on Global Food and Farming Futures (2011). He received an OBE in 2006 for services to sustainable agriculture, and an honorary degree from Ohio State University in 2009.

Professor David Richardson, University of East Anglia, UK (Organiser, Chair)
Professor David Richardson is the Dean of the Faculty of Science and Chair of Microbial Biochemistry in the School of Biological Sciences at UEA. He first came to UEA as a lecturer in 1991, he was then promoted to Reader in 1998, then Chair in 2001 and Dean in 2007. Prior to this David began his research career as a PhD student in the University of Birmingham (1985-88) and moved on to undertake post-doctoral research in the University of Oxford (1988-91).

David Richardson's research interests lie in the characterization of the microbiology and biochemistry of important biogeochemical mineral cycles, with particular focus on the nitrogen and iron cycles. David works in collaboration with colleagues in the Centre for Molecular and Structural Biochemistry to characterize biochemical reactions of these cycles in whole cells and cell communities, study gene expression and protein synthesis in response to key environmental parameters, study electron transfer between proteins involved in respiratory reactions of these cycles and purify and characterize the enzymes involved using spectroscopic and structural methodologies. The target organisms they study include soil bacteria, plant-symbiotic bacteria and pathogenic bacteria. Their work benefits from collaboration with colleagues working in the nearby Institute of Food Research and John Innes Centre. The work has implications for the release of globally important greenhouse gases such as nitrous oxide in agriculture, mechanisms of resistance to cytoxins, such as nitric oxide radicals, in pathogenic bacteria and can find application through the use of some of the enzymes involved in biosensors.

David Richardson was awarded the Fleming Medal in 1999 and he is a Royal Society Wolfson Merit Awardee.

Professor Yoshi Shiro, RIKEN SPring-8 Center, Japan (Speaker)
Yoshi Shiro was born in 1956 in Nagoya, Japan. He obtained the PhD degree, at Department of Chemistry, Kyoto University, Japan, in 1985. After the posdoc of JSPS (Japan Society for the Promotion of Science) for 2 year, he started his scientific career as the research scientist of RIKEN (Institute of Physical and Chemical

Research) in Japan. In 1990-91, Shiro stayed in Department of Chemistry, Stanford University, USA, as a visiting scholar. In 2000, he was appointed as the chief scientist, PI, of Biometal Science Laboratory of RIKEN SPring-8 Center. His research interests are dynamics of metals in biology, i.e., sensing, transportation, storage and utilization of metals in biology.

Professor Hirofumi Shoun, University of Tokyo, Japan (Speaker)
Hirofumi Shoun completed his doctoral studies in University of Tokyo with Kei Arima. Then in the same laboratory (microbiology and fermentation) he worked with Teruhiko Beppu on microbial oxygenases.

At University of Tsukuba, Japan, Hirofumi Shoun found denitrification by fungi (eukaryote) although it was then thought that only bacteria can participate in denitrification. Further, other novel nitrogen metabolisms by fungi, codenitrification and ammonia fermentation, were also found. He also showed that a cytochrome P450, termed P450nor, is involved in the fungal denitrification functioning as nitric oxide (NO) reductase. After returned to University of Tokyo, Shoun clarified the mechanism of nitrous oxide emissions from wastewater treatment plants, and showed a method to reduce the emissions. Thus he expanded enormously the nitrogen world of microorganisms.

Dr Steven Siciliano, University of Saskatchewan, Canada (Speaker)
Dr Steven D. Siciliano is an Associate Professor of Soil Toxicology at the University of Saskatchewan. Professor Siciliano is a world leading toxicologist investigating how polluted soil affects humans and ecosystem health. He has worked extensively across Canada's Arctic and Australia's Antarctic developing novel approaches to assessing soil toxicology in polar soil ecosystems. As part of these investigations, Professor Siciliano has worked extensively on the soil microbial ecosystems and how these ecosystems respond to abiotic and biotic stressors, such as climate change and pollution. In addition, Professor Siciliano has worked extensively in the biogeochemistry of mercury fate and transformation with a focus on how soil attributes influence aquatic fate processes. More recently, Professor Siciliano has focussed on brownfields with an emphasis on developing new toxicological models that will decrease the time and cost associated with site remediation and assessment. In 2006, Professor Siciliano was awarded a NSERC Discovery Accelerator award which recognizes outstanding researchers with a potential for world class breakthroughs. Professor Siciliano has published over 100 peer-reviewed book chapters and articles dealing with polluted soils and these contributions have been cited by other researchers over 2500 times.

Dr Ute Skiba, Centre for Ecology and Hydrology, Edinburgh, UK (Speaker)
Dr Ute Skiba, biogeochemist at the Centre for Ecology and Hydrology, Edinburgh has been studying the soil atmosphere exchange of trace gas fluxes, principally nitrous oxide, nitric oxide and methane for over 20 years.
Trace gas flux measurements, ranging from small soil cores studies to the landscape scale in a large range of temperate and tropical ecosystems, and more recently also from freshwaters and bioenergy crops, have lead to more than 78 peer reviewed papers on underlying processes and parameters controlling fluxes and upscaling to the ecosystem and the UK. The work is carried out in collaboration with international and national partners and funded by the EU (i.e.the IP 'Nitroeurope'), by DEFRA (i.e. 'Improving the agricultural nitrous oxide emission inventory'), NERC ('The present and future greenhouse gas budget of bioenergy crops in the UK') and others. Skiba has calculated nitrous oxide, methane and nitric oxide emission rates for national and European inventories (LULUCF, CORINAIR). He is section editor for Plant and Soil and member of the British Soil Science Society.

Professor Stephen Spiro, University of Edinburgh, UK (Speaker, Chair)
Stephen Spiro obtained a BSc in Molecular Biology from the University of Edinburgh (1984), and a PhD in Microbiology from the University of Sheffield (1988). His Ph.D. research was supervised by Professor John Guest, and involved the oxygen-sensitive transcriptional regulator FNR. After graduation, he remained in

Sheffield, first as a post-doctoral researcher, and then as an independent Research Fellow. In 1991, he took up a lectureship in the School of Biological Sciences at the University of East Anglia. In 2004, Stephen moved to an Associate Professor position in the School of Biology at the Georgia Institute of Technology, then in 2006 to the Department of Molecular and Cell Biology at the University of Texas at Dallas. In recent years, his research has focused on the mechanisms by which nitric oxide influences gene expression, both in *Escherichia coli*, and in the denitrifying organism *Paracoccus denitrificans*.

Professor Andrew Thomson OBE FRS, University of East Anglia, UK (Organiser)
After completing his doctoral studies in Oxford with RJP Williams, FRS, Andrew Thomson worked on the effect of platinum salts on bacterial growth processes in the laboratory of B Rosenberg, Michigan State University, between1965-67. His discovery of cis-dichlorodiammineplatinum(II), an potent inhibitor of cell division, led to its widespread clinical use as cis-Platin, a highly effective drug against testicular and other cancers.

At the University of East Anglia (UEA), Norwich, Andrew Thomson pioneered the development of magnetic circular dichroism (MCD) spectroscopy as a selective probe of the oxidation, spin and ligation states of metal cofactors in proteins. The method, together with electron paramagnetic resonance spectroscopy (EPR), both powerful in structural and mechanistic studies, was applied to a wide range of metallo-enzymes from the bacterial denitrification pathway. With the late Professor Colin Greenwood he established at UEA an interdisciplinary Centre for Metalloprotein Spectroscopy and Biology (CMSB) with faculty members drawn from the Schools of Biological and Chemical Sciences to explore the roles of transition metal ions in biological cells.

Professor Andrew Watson FRS, University of East Anglia, UK (Organiser)
Andrew Watson is a Royal Society Research Professor at the School of Environmental Sciences at the University of East Anglia, appointed to that position as part of the Royal Society's 350th anniversary. He researches the global carbon cycle, and the processes that affect Earth's atmospheric carbon dioxide, both through earth history and on the modern, human-disturbed planet. He studied planetary atmospheres at the University of Michigan, before returning to the UK and working at the Plymouth Marine Laboratory, where he developed tracer techniques that enabled large scale ocean experiments to study mixing, gas exchange, and the role of iron as a limiting nutrient. He is a Fellow of the Royal Society, a member of NERC council, and recipient of the European Geophysical Union's Nansen medal for achievements in marine science.

Professor Zhiguo Yuan, University of Queensland, Australia (Speaker)
Dr Zhiguo Yuan is professor in environmental engineering, and Deputy Director of the Advanced Water Management Centre at The University of Queensland, Australia. His main research topics are biological nutrient removal from wastewater, greenhouse gas emissions from wastewater systems including both collection and treatment systems, and corrosion and odour management in sewer networks.

Over the past 14 years, he has published over 150 journal papers and presented at numerous national and international conferences. His publications have attracted over 2000 citations to date. His current h-index is 26.

Prof Yuan is a senior editor of the IWA journal of Water Science and Technology. In July 2010, he was appointed one of the 34 inaugural IWA Fellows.

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EXCELLENCE IN SCIENCE

THE ROYAL SOCIETY

Participant List

Correct as of 16 May 2011

Title	Forename	Surname	Organisation
Mr	Umer	Afzal	University of Engineering and Technology Lahore, Pakistan
Professor	Illimar	Altosaar	Green Crop Network Canada, and University of Ottawa, Canada
Professor	Elizabeth	Baggs	University of Aberdeen, UK
Professor	Lars	Bakken	Norwegian University of Life Sciences, Norway
Dr	Hermann W	Bange	IFM-GEOMAR, Germany
Miss	Charlotte	Beard	Royal Society of Chemistry, UK
Dr	Sam	Bonnett	Harper Adams University College, UK
Miss	Sara	Burbi	Royal Agricultural College, UK
Dr	Laura	Cardenas	Rothamsted Research Ltd, UK
Dr	Glenn	Carver	University of Cambridge, UK
Mr	Yahia	Chergui	Annaba University, Algeria
Dr	Eric	Crosson	Picarro, Inc., USA
Professor	Paul	Crutzen	Max Planck Institute for Chemistry, Germany
Mr	Christian	Davies	Shell, UK
Professor	Bob	Eady	University of Liverpool, UK
Miss	Heather	Felgate	University of East Anglia, UK
Professor	David	Fowler CBE FRS	NERC Centre for Ecology and Hydrology, UK
Mr	Georgios	Giannopoulos	University of East Anglia, UK
Professor	Keith	Goulding	Rothamsted Research, UK
Dr	Simon	Gregory	Swansea University, UK
Ms	Stephanie	Griggs-Trevarthen	Oxford Brookes University, UK
Professor	Geoffrey	Hamer	Biofocus Foundation, uK
Dr	Neil	Harris	University of Cambridge, UK
Ms	Katherine	Hartop	University of East Anglia, UK
Dr	Ewa	Hartwell	University of East Anglia, UK
Dr	Mike	Harvey	(NIWA) National Institute for Water and Atmospheric Research, New Zealand
Mr	Gary	Hayes	hgen ltd, UK
Professor	Louise	Heathwaite	NERC and Lancaster Environment Centre, UK
Dr	Penny	Hirsch	Rothamsted Research, UK
Dr	Tony	Hooper	Rothamsted Research, UK
Miss	Aranzazu	Louro Lopez	Rothamsted Research Ltd, UK
Dr	Robin	Matthews	James Hutton Institute, UK
Dr	Martin	Milton	National Physical Laboratory, UK
Mr	Josep-Anton	Morguí	Institut Català de Ciències del Clima (IC·3), Spain
Dr	Nicholas	Morley	University of Aberdeen, UK

Professor	Isabel	Moura	Universidade Nova de Lisboa, Portugal
Ms	Harriet	Moyo	Royal Agricultural College, UK
Dr.	Sofia	Pauleta	REQUIMTE-CQFB, Portugal
Dr	Robert W	Portmann	National Oceanic and Atmospheric Administration, USA
Professor	Jules	Pretty	University of Essex, UK
Professor	David	Richardson	University of East Anglia, UK
Professor	Alan	Rodger	British Antarctic Survey, UK
Mr	Sebastian	Runkel	University of East Anglia, UK
Dr	Ruben	Sakrabani	Cranfield University, UK
Professor	Yoshi	Shiro	RIKEN SPring-8 Center, Japan
Professor	Hirofumi	Shoun	University of Tokyo, Japan
Dr	Steven	Siciliano	University of Saskatchewan, Canada
Dr	Ute	Skiba	NERC Centre for Ecology and Hydrology, UK
Mr	Marcin	Skiba	Scottish Crop Research Institute, UK
Dr	Kate	Smith	ADAS, UK
Professor	Stephen	Spiro	University of Texas at Dallas, USA
Dr	Clare	Stirling	Agriculture and Horticulture Development Board (the Home-Grown Cereals Authority), UK
Dr	Parvadha	Suntharalingam	University of East Anglia, UK
Professor	Roger	Sylvester-Bradley	ADAS, UK
Professor	Andrew	Thomson OBE FRS	University of East Anglia, UK
Dr	Rachel	Thorman	ADAS, UK
Dr	Isobel	Tomlinson	Soil Association, UK
Mr	Adam	Twine	The Farm Carbon-cutting Toolkit Community Interest Company, UK
Dr	Sami	Ullah	Keele University, UK
Miss	Kirsty	Watson	Cranfield University, UK
Professor	Andrew	Watson FRS	University of East Anglia, UK
Professor	Zhiguo	Yuan	The University of Queensland, Australia

Nitrous oxide, the forgotten greenhouse gas

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