Mark A. Sutton · Kate E. Mason ·
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Just Enough Nitrogen

Perspectives on how to get there for regions with too much and too little nitrogen

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Preface

The International Nitrogen Initiative—or INI for short—is a global network that focuses on bringing together scientific evidence to inform the development of policies and practices for better nitrogen management. In doing so, INI highlights a dual global challenge: that some regions of the world have excess nitrogen input, leading to major losses to the environment, while other regions have insufficient nitrogen input, constraining food production and exacerbating soil degradation including nitrogen depletion. It is therefore highly appropriate that the present volume seeks to bring these challenges together. It provides evidence to help local, national and global communities on how to get there with 'Just Enough Nitrogen'.

The setting for this discussion is also appropriate, as the volume represents the final outcomes from the 6th International Nitrogen Conference organized by the INI and hosted at the Speke Resort in Kampala, Uganda (24–27 November 2013). This was the first time that the International Nitrogen Conference was hosted in sub-Saharan Africa, as all previous conferences in the series had been organized in regions typified by excess nitrogen (Europe, North America, East Asia, Latin America, South Asia). The Kampala Conference therefore brought the INI community to a region where fertilizer inputs are typically less than one tenth of the rates per hectare in other world regions. With food security being one of the top issues for sub-Saharan Africa, and nitrogen supply being critical for food security, the conference therefore addressed a core challenge of the region. At the same time, the discussions set Africa in the global context, making the comparison with lessons learned in other regions.

The present volume reports the emerging messages. It builds on papers presented to the conference, including additional chapters that have been specifically developed after the conference as a result of the emerging discussions. The products include the conference declaration agreed by the delegates, representing a wide range of science and stakeholder interests, the *Kampala Statement-for-Action on Reactive Nitrogen in Africa and Globally*, together with the results of primary scientific studies and syntheses from local to regional and global scales. The subsequent analysis has also led to a chapter that assesses the impact of advance planning to halve meat intake, as compared with the reference intake for such a conference. The findings demonstrate how this demitarian approach greatly reduced the nitrogen footprint and environmental impact associated with the conference.

In launching this volume, we take the opportunity to thank all those who helped make the Kampala Conference such a success. In particular, we thank John Stephen Tenywa, Giregon Olupot, Patrick Musingusi, Peter Ebanyat, Trust Tumwesigye and colleagues in the local organizing committee. We thank the INI Coordination Team for its ongoing support, including Clare Howard, Will Brownlie, Agnieszka Becher and Sarah Blackman, together with the valuable support from Susan Greenwood-Etienne of the Scientific Committee on Problems of Environment (SCOPE).

We gratefully acknowledge the funding support from a wide range of sponsors for the conference, without whose support the endeavour would not have been possible. Together with the contributions-in-kind of many networks, we are grateful for conference funding from the Alliance for a Green Revolution in Africa (AGRA), the International Fertilizer Industry Association (IFA), the International Plant Nutrition Institute (IPNI), Africa Research in Sustainable Intensification for the Next Generation (Africa RISING), the National Agricultural Research Organisation of Uganda (NARO), the Department of Agricultural Production of Makerere University, the Global Partnership on Nutrient Management (GPNM) in cooperation with the Scientific Committee on Problems of Environment (SCOPE), the UK Centre for Ecology & Hydrology (UK CEH), the European Commission Joint Research Centre (JRC), the N2Africa project and the International Centre for Tropical Agriculture (CIAT).

We would also like to thank the Speke Resort, Kampala, for the additional work of sharing data on food supplies, comparison with a reference conference, and willingness to halve the normal amount of meat for the Nitrogen Conference. Last but not least, we thank all the authors, co-editors and chapter reviewers for their unstinting efforts at bringing the volume to such a high standard.

The outcomes provide serious food for thought. The volume shows how our food system is impacting all aspects of the global nitrogen cycle, contributing to climate change, air pollution, water pollution, and threatening human health, ecosystems and biodiversity. The chapters highlight how we need and benefit from nitrogen supply for food, yet the inefficient use of nitrogen—the majority of which is lost as pollution—is threatening our global environment. At the same time, rapidly increasing nitrogen oxide emissions from combustion sources in developing parts of the world point to a fast-growing threat, unless action is taken.

Together with the Kampala Statement-for-Action and an accompanying Special Issue of Environmental Research Letters, the present volume brings to completion the reporting of the Kampala Conference. Nevertheless, it is obvious that the challenge of solving the nitrogen challenge is just beginning. How indeed can we reach 'Just Enough Nitrogen'? With nitrogen cutting across most of the UN Sustainable Development Goals, humanity faces a global systemic challenge in the disruption of the world's nitrogen cycle. This systemic alteration points to the need for an equally transformational change to a global 'nitrogen circular economy', where efficient nitrogen use, food, health, wellbeing, environment and profit all go hand in hand.

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Acronyms and Abbreviations

AE	Agronomic Efficiency. Calculated in units of yield increase per unit of applied nutrient, such as nitrogen
AEZ	Agro-ecological Zone
AMF	Arbuscular Mycorrhizal Fungi
AUE	Agronomic Use Efficiency
BAT	Best Available Technique
BNF	Biological Nitrogen Fixation
C	Carbon
CAP	Common Agricultural Policy of the European Union
CBD	Convention of Biological Diversity
CCAC	Climate and Clean Air Coalition
CE	Capture Efficiency, i.e., the amount of a nutrient in the harvested product compared with the total nutrient uptake by the crop
CH_4	Methane
CL	Critical Loads
CO_2	Carbon dioxide
CPR	Committee of Permanent Representatives of the United Nations Environment Programme
CRIN	Cacao Research Institute of Nigeria
CT	Conventional Tillage
DAP	Di-ammonium phosphate, used as a mineral fertilizer
DM	Dry Matter
DMPP	3,4-dimethylpyrazole phosphate—a nitrification inhibitor
DNMARK	Danish Nitrogen Mitigation Assessment
DON	Dissolved Organic Nitrogen
EANET	Acid Deposition Monitoring Network in East Asia
EC	European Commission
[eCO_2]	Elevated CO_2 levels
EMEP	European Monitoring and Evaluation Programme

ENA	European Nitrogen Assessment
EPNB	Expert Panel on Nitrogen Budgets of the TFRN
ES	Ecosystem Services
EU	European Union
EU27	European Union 27 Member States
EU-NEP	European Union Expert Nitrogen Panel
FACE	Free Air Carbon dioxide Enrichment ecosystem manipulation system
FAO	Food and Agriculture Organization of the United Nations
FYM	Farmyard Manure
GAW	Global Atmospheric Watch
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GMO	Genetically Modified Organism
GN	Groundnut
GPA	Global Programme of Action for the Protection of the Marine Environment
GPNM	UNEP Global Partnership on Nutrient Management
GS	Glutamine Synthetase
HAB	Harmful Algal Bloom
HB	Haber-Bosch
HI	Harvest Index
HLPF	High-Level Political Forum on Sustainable Development
IITA	International Institute of Tropical Agriculture
INC	Internal Nitrogen Cycle
INE	Internal Nutrient Efficiency
ING-SCON	Indian Nitrogen Group under the Society for Conservation of Nature
INI	International Nitrogen Initiative
INMS	International Nitrogen Management System
INS	Indigenous Nutrient Supply
IOC-UNESCO	International Oceanographic Commission of of the United Nations Educational, Scientific and Cultural Organization
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ISFM	Integrated Soil Fertility Management
K	Potassium
KAP	Knowledge, Attitudes, Practices
LRTAP	UNECE Convention on Long-range Transboundary Air Pollution (informally the ‘UNECE Air Convention’)
m.a.s.l	Metres above sea level
miRNAs	Micro-Ribonucleic Acids

N	Nitrogen
N_2	Di-nitrogen, a colourless and odourless diatomic gas, forming about 78% of Earth's atmosphere
N_2O	Nitrous oxide—a powerful greenhouse gas
NB	(Partial) Nitrogen Balance, i.e., the difference between inputs (e.g., fertilizer, biological nitrogen fixation, manure) and outputs (crop harvest and other removed residues). May be defined at field, farm and regional scales
NBPT	N-(n-butyl) thiophosphoric triamide—a urease inhibitor that slows the conversion of urea to NH_x
NCE	Nitrogen Capture Efficiency, the amount of nitrogen taken up or 'captured' by a crop as a fraction of the N added as input to the soil (i.e., 'availability') from external supply and internal supply (mineralization)
NEWS India-UK	Indo-UK Virtual Nitrogen Centre on Nitrogen Efficiency in Whole-cropping Systems
NF_3	Nitrogen trifluoride
NGO	Non-governmental Organisation
NH_3	Ammonia—an air and water pollutant and the primary nitrogen form in biological systems.
NH_4^+	Ammonium—present in biological systems and soils, while forming a pollutant in atmospheric PM and aquatic systems
NH_x	Total ammoniacal nitrogen sometimes referred to as TAN
NI	Nitrification Inhibitor
Nnet	Nitrogen Human Environment Network
NO	Nitric oxide—a tropospheric air pollutant
NO_2	Nitrogen dioxide—a tropospheric air pollutant
NO_3^-	Nitrate—present as a secondary pollutant in atmospheric PM and a eutrophying pollutant of aquatic systems
NO_x	Nitrogen oxides—a combination of NO and NO_2
NPK	Nitrogen, Phosphorus and Potassium in combination
N_r	Reactive Nitrogen, a term used for a variety of nitrogen compounds that support growth directly or indirectly, as opposed to N_2 which is inert
NUE	Nitrogen Use Efficiency. Typically defined as the ratio of N in outputs divided by the N in inputs. May be defined for different systems such as crops, livestock, food chain and the whole economy
O_3	Ozone
OECD	Organization for Economic Co-operation and Development
P	Phosphorus
PM	Particulate Matter, which includes NH_4^+ and NO_3^- as major components; PM_{10} and $PM_{2.5}$ refer to atmospheric particulate matter (PM) that has a diameter of less than 10 and 2.5 μm respectively. PM_2 is also known as Fine Particulate Matter

POM	Particulate Organic Matter
PP	Pigeonpea
PUE	Phosphorus Use Efficiency
RCBD	Randomized Complete Block Design
RE	Recovery Efficiency, i.e., mass increase of nutrients in harvested crop as a fraction of the mass of nutrients applied
RF	Rain-Fed
RNA	Ribonucleic acid
SACEP	South Asia Co-operative Environment Programme
SANC	South Asian Nitrogen Centre
SDGs	Sustainable Development Goals
SI	Supplemental Irrigation
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
SSC	Soil Supply Capacity, i.e., ability of the soil system to replenish a given plant nutrient in the soil solution for plant uptake
STFR	Soil Testing and Fertilizer Recommendation
TAN	Total Ammoniacal Nitrogen
TFRN	Task Force on Reactive Nitrogen of the UNECE Convention on Long-range Transboundary Air Pollution
TN	Total Nitrogen
TR	Tied Ridges
TSP	Triple Super Phosphate
UN	United Nations
UNDP	United Nations Development Programme
UNDSD	United Nations Division for Sustainable Development
UNEA	United Nations Environment Assembly
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework on Climate Change
UNIDO	United Nations Industrial Development Organization
USD	United States Dollars (US$)
VCR	Value-Cost Ratio, i.e., the ratio of the price of additional yield (e.g., crop yield increment) following application of inputs (e.g., fertilizer, but excluding seeds) to the cost of the inputs
WHO	World Health Organization
WMO	World Meteorological Organization

Chapter 1
Just Enough Nitrogen: Summary and Synthesis of Outcomes

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Abstract Food production and power generation have increased to feed growing populations and to keep pace with economic development, leading to major human alteration of the global nitrogen (N) cycle. The result is a global challenge, with many regions having 'too much' or 'too little' nitrogen. As di-nitrogen (N_2) in the atmosphere, nitrogen is one of the most abundant elements, but which cannot be used

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by most organisms. Conversely, reactive nitrogen (N_r) is essential for organisms, but is mostly in short supply for natural ecosystems. Human activities have polarized the differences in N_r flows between different world regions, leading to major sustainability challenges, with implications for food security, adverse impacts on health and ecosystems, and the need to develop tools and policies for better management. In developed regions, abundant use of manufactured fertilizers, crop biological nitrogen fixation and inadvertent formation of nitrogen oxides via combustion processes are leading to a plethora of environmental problems. These threaten air quality, water quality, soil quality, greenhouse gas balance, stratospheric ozone levels, biodiversity and human health. At the same time, in many developing regions, insufficient access to reactive nitrogen is leading to degradation of agricultural soils including N depletion, making it vital to reduce losses and recycle available nitrogen stocks. Nitrogen emissions as a result of agricultural practices and combustion for energy represent a major economic loss. Adding up all N losses in the world (excluding emissions from oceans) amounts to a lost agricultural fertilizer resource worth around $200 billion USD annually. The societal costs to human health, ecosystems and climate are even larger at $400–4000 billion USD annually. Knowledge of these figures can help motivate society to optimize with 'just enough' nitrogen. This chapter provides an overview of results from the 6th International Nitrogen Conference, Kampala (Uganda), which considered the question of how to optimize practices for 'just enough' nitrogen both internationally and specifically for the African Continent. From experimental trials to scenario analysis, the contributions demonstrate the approaches being used. The messages in very different regions often turn out to be surprisingly similar. They encompass all aspects of society: optimizing the use of available fertilizer and manure resources (both under excess and under scarcity conditions), improving nitrogen use efficiency, developing landscape integration, and optimizing our food choices by prior planning that can also reduce food waste. Together, such nitrogen-related strategies will have major benefits for global environmental sustainability.

Keywords Nitrogen · Environment · Nitrogen use efficiency · Regional assessment · Environmental economics · Pollution mitigation strategies

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