Our Nutrient World

The challenge to produce more food and energy with less pollution

Executive Summary

Prepared by the Global Partnership on Nutrient Management in collaboration with the International Nitrogen Initiative

Global Overview on Nutrient Management

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The challenge to produce more food and energy with less pollution

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Executive Summary

Key Points

Nutrient Benefits and Threats

- The sustainability of our world depends fundamentally on nutrients. In order to feed 7 billion people, humans have more than doubled global land-based cycling of nitrogen (N) and phosphorus (P).
- The world's N and P cycles are now out of balance, causing major environmental, health and economic problems that have received far too little attention.
- Insufficient access to nutrients still limits food production and contributes to land degradation in some parts of the world, while finite P reserves represent a potential risk for future global food security, pointing to the need for their prudent use.
- Unless action is taken, increases in population and per capita consumption of energy and animal products will exacerbate nutrient losses, pollution levels and land degradation, further threatening the quality of our water, air and soils, affecting climate and biodiversity.

The Nutrient Challenge

- *A new global effort is needed to address 'The Nutrient Nexus', where reduced nutrient losses and improved nutrient use efficiency across all sectors simultaneously provide the foundation for a Greener Economy to produce more food and energy while reducing environmental pollution.*
- The new effort must cross the boundaries between economic sectors and environmental media, be underpinned by scientific and other evidence from a robust global assessment process, share best practices, and address the substantial cultural and economic barriers that currently limit adoption.

Actions and Outcomes

- *The global community of all relevant stakeholders now needs to agree which existing inter-governmental process is best suited to take the lead in improving nutrient management for the 21st century, or whether a new policy process is needed.*
- One option is to strengthen the mandate of the 'Global Programme of Action for the Protection of the Marine Environment from Land-based Activities' (GPA) to address the inter-linkages between land, air and water, in relation to the global supply of all nutrient sources and Nutrient Use Efficiency (NUE) across the full chain, considering their regional variation.
- Nutrient Use Efficiency represents a key indicator to assess progress towards better nutrient management. An aspirational goal for a 20% relative improvement in full-chain NUE by 2020 would lead to an annual saving of around 20 million tonnes of nitrogen ('20:20 by 2020'), and equate to an initial estimate of improvement in human health, climate and biodiversity worth around $170 billion per year.

Developing the Mandate

- A central objective of the new inter-governmental effort must be to show how improved management of N and P at different scales over the whole cycle would simultaneously make quantified contributions toward meeting existing commitments for water, air, soil, climate and biodiversity, while underpinning improved food and energy security – with net social and economic benefits.
- *International consensus and authorization of the global nutrient focus is now essential, emphasizing the need for a mandate to assess the scientific evidence, share best practices, and work towards inter-governmental agreements that make quantifiable steps toward the sustainable development of Our Nutrient World.*

Too much and too little nutrients

Nutrients feed the world

1. The world needs nutrients, especially nitrogen (N) and phosphorus (P), which are essential to raise crops and animals to feed an increasing world population (Chapters 1 and 2).
   - It is estimated that nitrogen and other mineral fertilizer is essential to feed around half of the world's population, and will be fundamental to ensure global food security through the 21st century.
   - Natural nutrient sources and recycling have been insufficient for increasing human needs since the 19th century. The 18th-19th century agricultural and industrial revolutions laid the foundation for exploitation of mined sources of N and P, and for development of the Haber-Bosch process, where energy is used to convert otherwise unreactive atmospheric di-nitrogen (N_2) into reactive nitrogen (N_r) compounds.
   - The 20th century 'green revolution' has depended critically on these additional nutrient sources, while becoming the basis for an ongoing 'livestock revolution', where relatively cheap grain and other produce (surplus to regional food requirements) are allowing intensification of livestock farming, greatly increasing per-capita meat and dairy production.
   - While recent trends in nutrient consumption are relatively stable in developed countries, growing human population and rising per capita meat/dairy consumption as a result of increasing incomes are together causing a rapid increase in nutrient consumption in transitional and developing countries. It is anticipated that these countries may account for ¾ of global nutrient consumption by 2050.
   - Around 2% of world energy use is dedicated specifically to the industrial manufacture of N_r, mainly through the Haber-Bosch process, so that N_r prices are closely coupled to global energy prices.
   - Phosphorus is obtained from mining of finite phosphate rock deposits, with current world supplies coming from just a few key countries. This poses potential risks for future supply, given that there is no alternative to P as an essential plant nutrient. Parallel risks apply for other mined nutrients including potassium (K) and micronutrients, especially zinc, for which the currently identified resources have a much shorter lifetime than for phosphorus and potassium.

Nutrient losses create a global web of pollution

2. There are major problems associated with high levels of nutrient use, especially in Europe, North America, South and East Asia and Latin America (Chapters 3, 4 and 8).
   - The efficiency of nutrient use is very low: considering the full chain, on average over 80% of N and 25-75% of P consumed (where not temporarily stored in agricultural soils) end up lost to the environment, wasting the energy used to prepare them, and causing pollution through emissions of the greenhouse gas nitrous oxide (N_2O) and ammonia (NH_3) to the atmosphere, plus losses of nitrate (NO_3^-), phosphate (PO_4^{3-}) and organic N, P compounds to water.
   - Oversupply of nutrients, or imbalance between nutrients, reduces the efficiency of nutrient use. Efficiency is further reduced by including livestock in the food chain, substantially increasing N and P pollution levels.
   - Burning fossil fuels produces a significant additional N_r resource (~20% of human N_r production) part of which could be captured and used, but which is currently wasted as emissions of nitrogen oxide (NO_x) to air, contributing to particulate matter and ground-level (tropospheric) ozone, which adversely affect human health, ecosystems and food production systems.
   - Many thresholds for human and ecosystem health have been exceeded due to N_r pollution. Each of these environmental effects can be magnified by the 'nitrogen cascade', where a single atom of N_r can trigger a cascade of negative environmental impacts.

Insufficient nutrients exacerbate land degradation

3. In Africa, Latin America and parts of Asia there are still wide regions with too little nutrients. In particular (Chapters 2 and 4):
   - Many farmers do not have access to affordable mineral fertilizers, where lack of local sources and poor supply infrastructure increases prices, limiting agricultural yields. Biological nitrogen fixation and manure recycling are key local nutrient sources which are not always optimally exploited.
   - The inability to match crop harvests with a sufficient nutrient return leads to depletion of nutrients and organic matter, reducing soil quality and increasing the risk of land degradation through erosion and of agricultural incursion into virgin ecosystems.
   - Shortages of water and micronutrients (such as sulphur, zinc, selenium, etc.) can limit N and P use efficiency, preventing the best use being made of these major nutrients.

Key Nutrient Threats

4. Five main threats of nitrogen pollution were highlighted by the European Nitrogen Assessment (Chapter 4). These are adapted here to reflect the

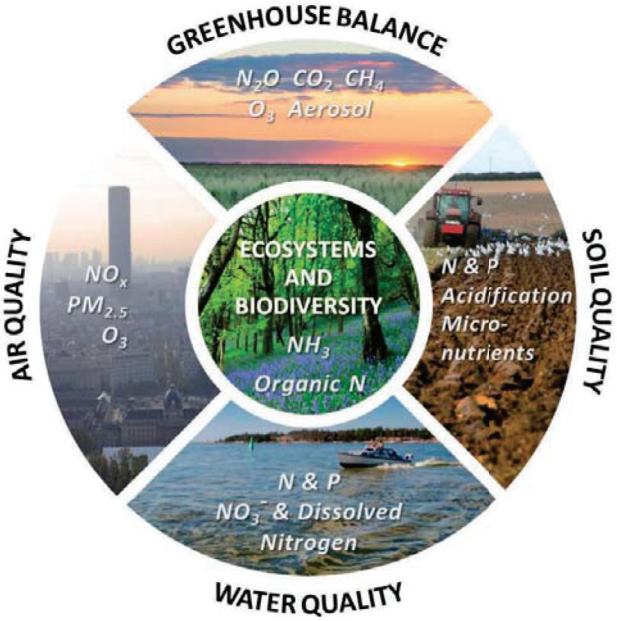

Figure ES1 The five key threats of too much or too little nutrients (Chapter 4).

global environmental nutrient threats (Figure ES1), highlighting the complexity of nutrient interactions, while offering a short-list of the 5 key issues.

5. This short list of key environmental threats forms the WAGES of too much or too little nutrients:
   - Water quality – including coastal and freshwater dead zones, hypoxia, fish kills, algal blooms, nitrate contaminated aquifers and impure drinking water, resulting from both N_r and P eutrophication.
   - Air quality – including shortening of human life through exposure to air pollutants including particulate matter formed from NO_x and NH_3 emissions, and from increased concentrations of nitrogen dioxide (NO_2) and ground-level ozone (O_3).
   - Greenhouse gas balance – including emissions of N_2O plus interactions with other N_r forms, particulate matter and atmospheric N_r deposition, plus tropospheric O_3. N_2O is now also the main cause of stratospheric ozone depletion, increasing the risk of skin cancer from UV-B radiation.
   - Ecosystems and biodiversity – including the loss of species of high conservation value naturally adapted to few nutrients. Eutrophication from atmospheric N_r deposition is an insidious pressure that threatens the biodiversity of many 'protected' natural ecosystems.
   - Soil quality – over-fertilization and too much atmospheric N_r deposition acidify natural and agricultural soils, while a shortage of N and P nutrients leads to soil degradation, which can be exacerbated by a shortage of micronutrients, leading to loss of fertility and erosion.
6. The increased release of N and P into our environment can be seen in relation to present efforts to refine 'Planetary Boundaries' for key global threats. The huge extent to which N_r production and releases exceed the boundary has already been widely publicized. Efforts are now needed to improve the dose-response relationships and quantify regional variation. This will enable the fine tuning of response, while noting that sufficient evidence is already available to justify taking action to reduce these threats.

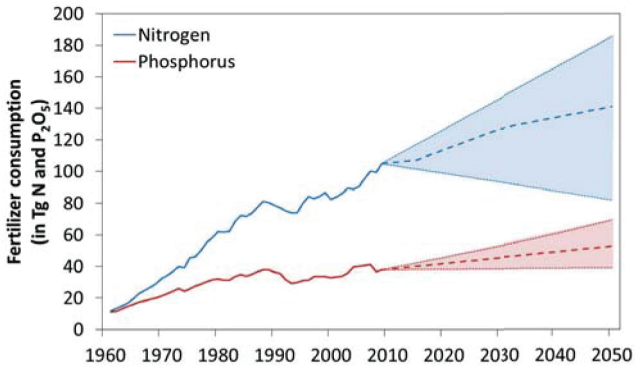

Figure ES2 Trends in global mineral fertilizer consumption for nitrogen and phosphorus and projected possible futures. The amounts of N and P in 2050 will depend on present-day decisions (expressed as N and P_2O_5) (Chapter 2).

Nutrients are an increasing threat requiring urgent action

7. Since the 1960s, human use of synthetic N fertilizers has increased 9-fold globally, while P use has tripled (Chapter 2). Further substantial increase of around 40-50% is expected over the next 40 years (Figure ES2) in order to feed the growing world population and because of current trends in dietary lifestyles, with increasing consumption of animal products. These changes will exacerbate current environmental problems unless urgent action is taken to improve the efficiency of N and P use, and to re-evaluate societal ambitions for future per capita consumption patterns.
8. The consequences of not taking action include further global warming effects from increasing atmospheric N_2O (a greenhouse gas which is 300 times more radiatively reactive than CO_2), continuing deterioration of water, air and soil quality, shortening human life, while threatening ecosystem services and biodiversity. The full damage cost has not yet been assessed, but annual global loss of ecosystem services including damage to fisheries from coastal N and P pollution-related hypoxia alone costs an estimated $170 billion

(Chapter 5). Making better use of nutrients will reduce these pollution threats, while improving food and energy production.

9. The possibility of P shortage in the future represents a major issue of recent contention (Chapter 2). Global supply security of P is a prerequisite for food security. While only 3 countries produce 66% of rock phosphate, many countries do not have the physical reserves or economic means to obtain them. There are few countries whose known reserves cover current P demand for a long period (e.g. Morocco, Algeria: >1000 years based on current use and reserve estimates), others for a shorter time (USA, China, Brazil: 50 years), while other countries have no notable reserves (e.g. Germany, Japan). Whether there are accessible global P reserves to feed humanity for decades or centuries, long-term access to P is a critical issue that calls for more efficient practices and consumption patterns that waste less nutrients and minimize environmental impacts.
10. The risk of future shortage of potassium, and of zinc and other essential micronutrients needs to be further investigated, especially as only 20 years of zinc reserve are currently identified (roughly maintaining this number since the 1980s, as new reserves have been identified) (Chapter 2).

Solutions must address N and P cycles on local to global scales

11. Nitrogen and phosphorus cycles operate across multiple spatial scales, from the dynamics of a single field, through trans-boundary transport of air and water pollution, to the global increase in N_2O concentrations. Such inter-connections require consensus on an international approach that takes account of local and regional conditions, while addressing the necessary improvement in nutrient use efficiency at the global scale. The role of 'barriers to change' also necessitates a global approach. These include the global scale of trade in mineral fertilizers, food crops, animal feed and livestock products, which can constrain the adoption of nutrient best practices (Chapters 7 and 8).
12. Major inequalities exist between those parts of the world using excess nutrients and those that do not have enough. The key regions where too much nutrients are typically used include North America, Europe, and parts of South and South East Asia and Latin America. By contrast, many parts of Africa and Latin America have insufficient access to nutrients, leading to soil nutrient mining and limiting productivity. The scale of the differences is illustrated for major river catchments in Figure ES3, with these being exacerbated by differences in nutrient use efficiency across the full chain.

Key actions to produce more food and energy with less pollution

13. We identify ten key actions as being central to improving nutrient use efficiency, thereby improving food and energy production, while reducing N and P losses that pollute our environment (Chapter 6).

Agriculture

1. Improving nutrient use efficiency in crop production,
2. Improving nutrient use efficiency in animal production,
3. Increasing the fertilizer equivalence value of animal manure,

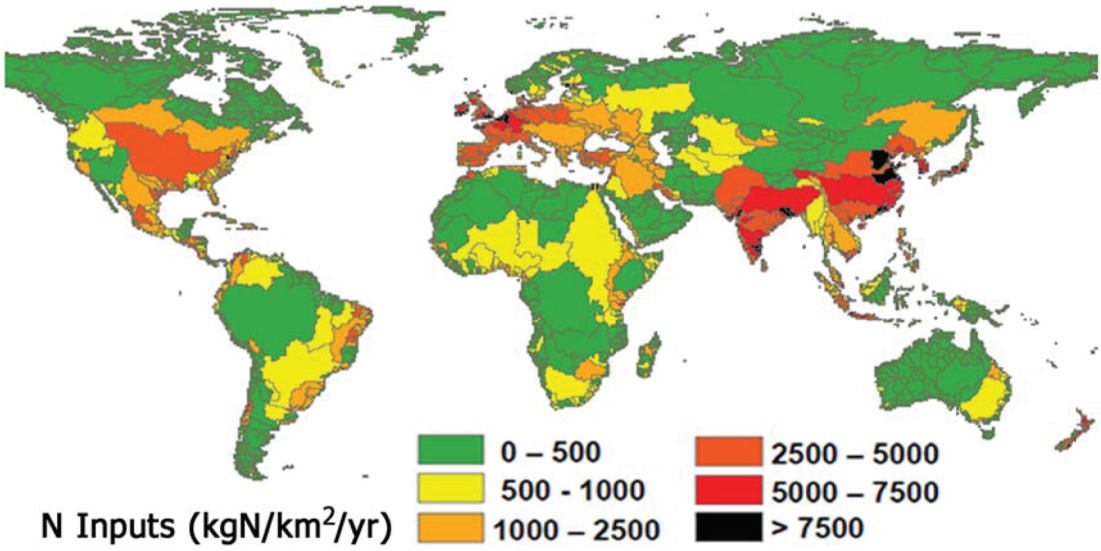

Figure ES3 Some regions use excess nutrients, with the waste causing environmental pollution, while other regions do not have enough. The map shows estimated net anthropogenic nitrogen inputs according to the world's main river catchments (Chapter 3).

Transport and Industry

4. Low-emission combustion and energy-efficient systems, including renewable sources,
5. Development of NO_x capture and utilization technology,

Waste and Recycling

6. Improving nutrient efficiency in fertilizer and food supply and reducing food waste,
7. Recycling nitrogen and phosphorus from waste water systems, in cities, agriculture and industry,

Societal consumption patterns

8. Energy and transport saving,
9. Lowering personal consumption of animal protein among populations consuming high rates (avoiding excess and voluntary reduction),

Integration and optimization

10. Spatial and temporal optimization of nutrient flows.

14. These actions must be seen in the context of the wider N and P cycles, considering acquisition, use and recycling. Efforts are needed to improve the nutrient use efficiency (NUE) of each stage, such as in crop and animal production. However, *we emphasize the need to address the 'full-chain NUE'*, defined as the ratio of nutrients in final products (e.g., human food consumed) to new nutrient inputs (e.g., Haber-Bosch N_r, biological N fixation, NO_x formation, mined P and N).
15. As Figure ES4 illustrates, each of the component efficiencies contribute to the full-chain NUE. Actions *promoting the recycling of available N_r and P pools*, such as effective recycling of animal manures, human sewage and NO_x capture and utilization (NCU) technology, all contribute to increasing full-chain NUE. The options include many technical measures, such as improved placement and timing for mineral fertilizer and organic manures, the use of manure storage and spreading methods that reduce emissions, and the processing of manures into more efficient fertilizers.
16. Where we can, *our choices as citizens* make a big difference. While some remain undernourished, people in many countries eat more animal products than is optimal for a healthy diet. Avoiding over-consumption of animal products (e.g., staying within World Health Organization guidelines for saturated fats) increases full-chain NUE, reducing N and P pollution, while benefiting our health. There are many opportunities for citizens of wealthy countries to show how consuming less animal products can lead the way toward future lifestyles where better dietary health and environmental quality go hand-in-hand.
17. The global economic benefits for the environment and human health by *avoiding over-consumption of animal products* still need to be quantified. However, the central role of livestock in contributing to nutrient pollution is well established. In the European Nitrogen Assessment, it was estimated that 85% of harvested N_r was used to feed livestock, with only 15% feeding people directly, while the average EU citizen consumed 70% more protein than needed for a healthy diet.

A new intergovernmental focus

18. There is an urgent need to develop joined-up approaches that optimize the planet's nutrient cycles for delivery of our food and energy needs, while reducing threats to social and economic well being, including threats to climate, ecosystem services and human health. This set of multiple connections may be termed 'The Nutrient Nexus', where good nutrient management can be seen as making a vital contribution to all global change challenges (Chapter 7).
19. Nutrient management is currently addressed in part by divergent efforts on food, climate, water and air pollution, and biodiversity, but there is no international treaty that links the major nutrient benefits and threats (Chapters 7 and 8).
20. Existing N and P policies have been most successful in sectors consisting of few key actors (e.g. electricity generation, car manufacturing, water treatment), but have made less progress when engaging many diverse actors (e.g., citizens' transport choices, farmer practices). The challenge of diversity requires long-term dialogue, education and training, especially utilizing key actors in nutrient pathways.
21. One option to address the Nutrient Nexus would be to strengthen the mandate of the intergovernmental 'Global Programme of Action for the Protection of the Marine Environment from Land-based Activities' (GPA). Although GPA has a current focus on the marine environment, it is already taking a lead in developing a cross-sectoral approach through the Global Partnership on Nutrient Management (GPNM).
22. International consensus is now needed (Chapter 8) that mandates a strengthened GPA or other body to:
    1. **Establish a global assessment process for nitrogen, phosphorus and other nutrient interactions**, between air, land, water, climate and biodiversity, considering the main driving forces, the interactions with food and energy security, the costs and benefits and the opportunities for the Green Economy,
    2. **Develop consensus on the operational indicators**, with benchmarking to record progress on improving nutrient use efficiency and reducing the adverse environmental impacts,
    3. **Investigate options for improvement of nutrient use efficiency**, demonstrating benefits for health, environment, and the supply of food and energy,
    4. **Address barriers to change**, fostering education, multi-stakeholder discourse and public awareness,

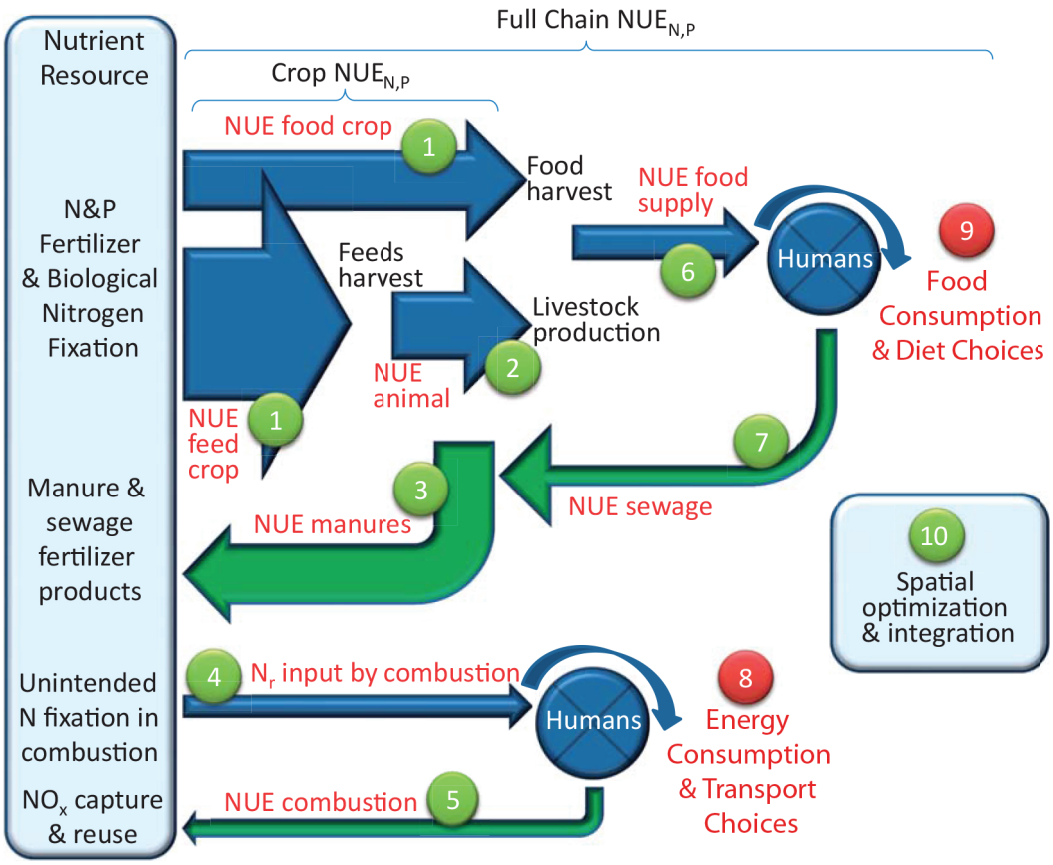

Figure ES4 Nutrient flow can be seen as a cycle from resource through the stages of use (blue arrows) with recycling (green arrows). The system is driven by the 'motors' of human consumption. Numbered circles highlight the ten key actions to increase Nutrient Use Efficiency (NUE) (Chapter 6).

5. **Establish internationally agreed targets for improved N_r and P management** at regional and planetary scales,
6. **Quantify the multiple benefits of meeting the nutrient management targets** for marine, freshwater and terrestrial ecosystems, mitigation of greenhouse gases and other climate threats, and improvement of human health,
7. **Develop and implement an approach for monitoring** time-bound achievement of the nutrient management targets, and for sharing and diffusing new technologies and practices that would help to achieve the targets.

23. An illustration of projected achievable gains is shown in Figure ES5. Globally, a target for 2020 to achieve a relative improvement in full-chain nutrient use efficiency by 20% would deliver an estimated saving of 20 million tonnes of N_r. Based on initial estimates, this would equate to a global improvement in human health, climate and biodiversity of the order of $170 (50-400) billion per year (Chapter 8).

24. A 20% improvement in full-chain NUE while maintaining current levels of N input would give smaller net benefits 70 (15 – 165), with environmental benefits much larger than implementation cost, although this figure does not include the substantial additional benefits of increased food and energy production.

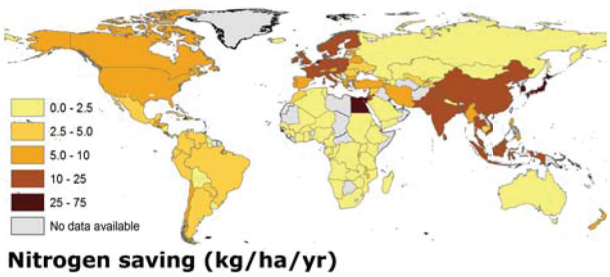

Figure ES5 The benefits of improved Nutrient Use Efficiency (NUE). The map shows the N_r savings that would be made, per ha of agricultural land, from a 20% relative improvement in full-chain NUE (see Chapter 8).

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