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Addressing the Nutrient Challenge: Where we are, what we need to know and what we need to do?

Note by the Secretariat

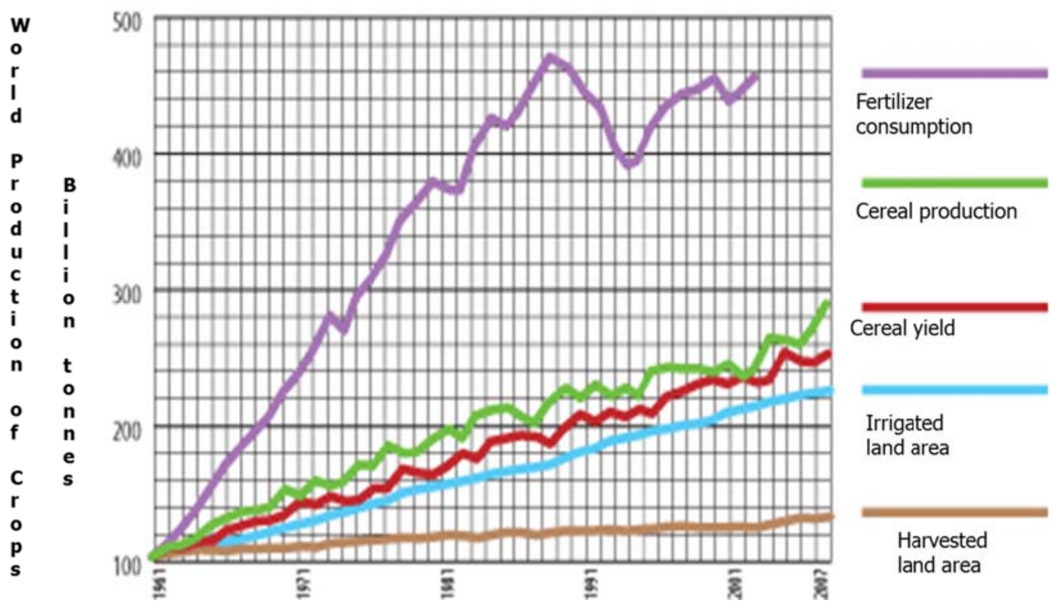
The present document has been issued without formal editing.

Addressing the Nutrient Challenge:
Where we are, what we need to know and what we need to do?

What is the challenge and where are we?

1. Nutrients: nitrogen and phosphorus are key to growing crops and thus play a major role in the world's food security challenge. To feed a growing world population, it is argued that "we have no option but to intensify crop production" (FAO 2011),[1] and food security of two-thirds of the world's population depends on fertilizers availability and use. Many approaches and policy measures have been applied and/or put in place to support agricultural intensification. The Green Revolution is credited, by many for its contribution to reduction of poverty in many parts of the world and is believed to have saved large areas of fragile land from conversion to extensive farming. The FAO study cited above notes that "over the past half-century, since the advent of the Green Revolution, world annual production of cereals, coarse grains, roots and tubers, pulses and oil crops has grown from 1.8 billion tonnes to 4.6 billion tonnes. Growth in cereal yields and lower cereal prices significantly reduced food insecurity in the 1970s and 1980s, when the number of undernourished actually fell, despite relatively rapid population growth. Overall, the proportion of undernourished in the world population declined from 26 percent to 14 percent between 1969-1971 and 2000-2002" (ibid. 4-5). However, UNEP Year Book 2011, referring to several recent studies and UN General Assembly proceedings noted that hunger and malnutrition increased between 2007 and 2009, particularly reversing earlier progress, and the report highlighted that "many of the world's estimated 925 million undernourished people are small-scale farmers" (UNEP 2011:37).[2] The figures below (1-3) show trends in fertilizer use, cereal production and land area under crop production over time.

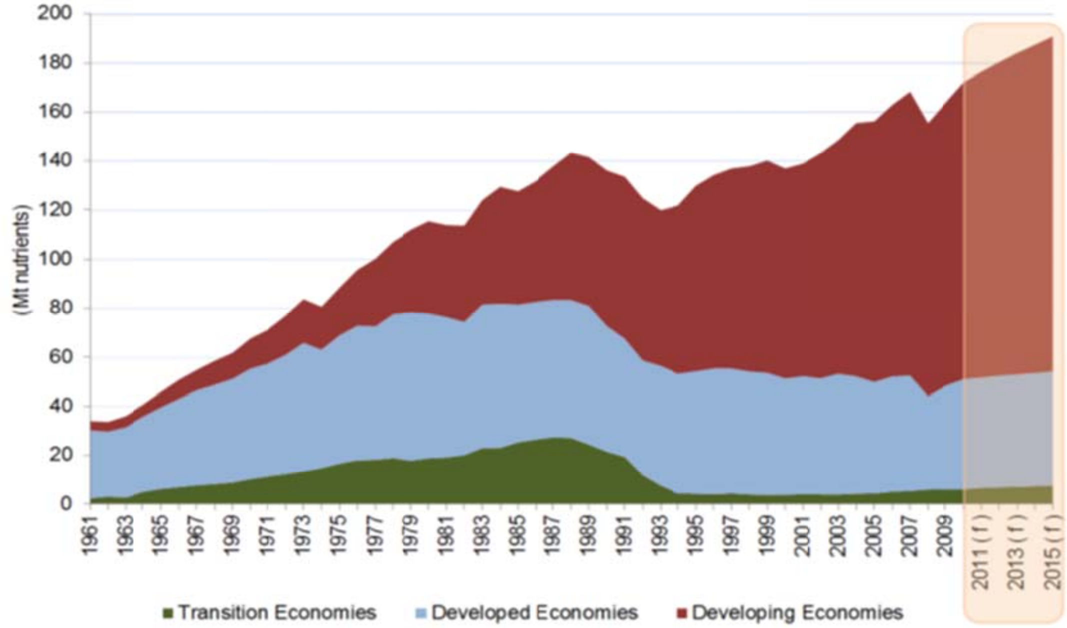
Figure 1: Indicators of global crop production intensification, 1961-2007
Index (1961=100)



Source: FAO 2011. Save and Grow

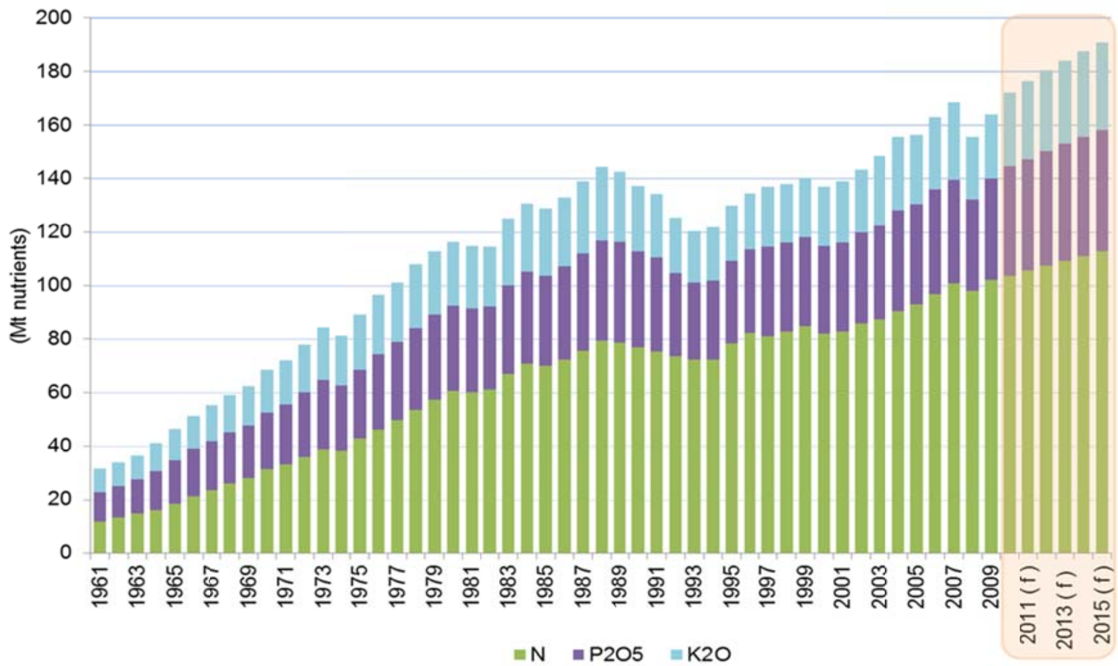
[1] FAO: 2011. Save and Grow. A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production. Rome.
[2] UNEP 2011 report refers to International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD 2009) report 'Agriculture at a Crossroads: synthesis report", FAO (2010) report The State of Food Security in the World 2010: addressing food insecurity in protected cities, and UN GA (2010) Keeping the promise: United to achieve the MDGs. A forward looking review to promote an agreed action agenda to achieve the Millennium Development Goals by 2015. UNGA 64/665.

Figure 2: World Fertilizer Consumption ((Mt nutrients) by Region overtime: 1961-2009



Source: IFA 2011 Agriculture (**Note:** Almost all the contraction of world fertilizer consumption in the early 1990s was due to disintegration of the former Soviet Union)

Figure 3: World Fertilizer Consumption (Mt nutrients) by Nutrient over time: 1961-2009



Nutrients	2009 (000 tonnes)	1961(‘000 tonnes)
Nitrogen	102,263.3	11,784.4
Phosphate	37,645.4	11,037.4
Potash	23,953.2	8,836.4

Source: IFA 2011 Agriculture

2. Nitrogen use if properly managed enhances soil fertility, and contributes to food and nutrition security and sustainable agriculture. However, when improperly managed, it can be associated with a number of adverse effects on both human health and the environment. Nitrogen fertilizer application is an essential component of increased food, feed and fiber production, and has made a substantial contribution to the tripling of global food production over the last 50 years. Its overuse is now believed to be responsible for numerous problems directly related to human health and environmental problems. This is mainly due to low nitrogen use efficiency (NUE) of applied nitrogen fertilizers. Lack of reactive nitrogen in the ecosystem leads to decline in soil fertility due to depletion of organic matter, soil erosion, and in extreme cases desertification and ultimately to low yields and crop protein content. Furthermore, empirical evidences suggest that generally fertilizers are often over-applied or applied when they cannot be effectively utilized by crops, even in areas of overall nutrient shortage.

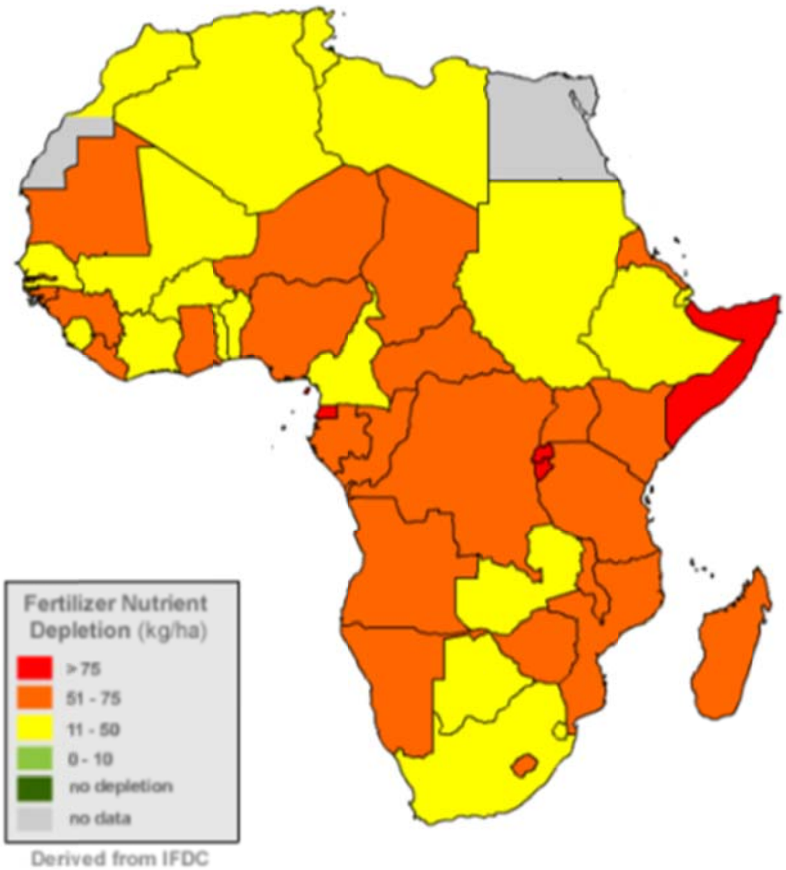
3. On average, a crop takes up only 20 to 50 percent of the nitrogen applied for the production of upland cereal crops, and in rice production, NUEs of 30 percent or lower are typical in many regions (Mosier et al.eds.2004:5).[3] While in some parts of the world, there is overuse of nutrients, in other parts, for instance, in Africa, the farmers do not have access to enough nutrients to grow crops and feed the growing population. Both situations (too much or too little) can lead to numerous problems. Limited application of nutrients in Africa has contributed to the decline in soil fertility through the depletion of nutrients, loss of soil organic matter (see Map 1), very low crop yield, food insecurity and soil erosion.

4. Against this backdrop, farmers continue to bring marginal lands under production to meet food demands of a growing population resulting in land degradation and often times deforestation. The excess nutrients in the environment in other parts of the world, as a result of industrial and agricultural activity has created profound impacts, in particular the pollution of water supplies as well as creation of dead zones (eutrophication) in the oceans and thus undermining the important ecosystems and the services and livelihoods they support. Other impacts include air pollution and climate change. The global loss of ecosystem services due to nutrient over-enrichment of the coastal waters amounts to nearly USD 200 billion per annum according to some estimates.[4]

[3] Agriculture and the Nitrogen Cycle. Assessing the impacts of fertilizer use on food production and the environment. SCOPE Series 65. Island Press. 2004.

[4] Robert Díaz and Michael Kemp 2010. Presentation made in the Second Expert Group Consultation on Hypoxia organized by the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility in Washington DC, June 16-17.

Map 1: Nutrient depletion rates in Africa



5. The result of this is a seeming divide between societal needs for food and energy and a complex web of adverse environmental impacts. This divide, ‘the nutrient challenge’, is set to intensify, to the cost of countries, as population, urbanisation and food and energy demands increase and lifestyles change (see Box 1).

6. In all areas, and especially in agriculture, there is significant scope for more efficient use of nutrients with subsequent benefits to farmers in maximising their profitability from fertilizers. Increased efficiency and best management practices result better yields and cost savings, freeing-up valuable cash resources and sustenance of the ecosystems services which have profound benefits for the livelihoods of people. In Box 1, some key facts are noted to set the context and visualize the challenge that we are facing.

Box 1: The global 'Nutrient Challenge' some key facts that we need to know

Human activities produce around 120m tonnes of reactive nitrogen each year, much of which (nearly two thirds) ends up polluting air, water, soil marine and coastal areas, and adding harmful gases to the atmosphere.

Some 20m tonnes of phosphorus are mined every year and nearly half enters the world's oceans - 8 times the natural rate of input.

Between 1961 and 2009 global use of synthetic nitrogen fertilizer increased nearly nine fold, while phosphorus use more than tripled (see Figure 3).

Two thirds of the world's population is now thought to depend on nitrogen and phosphorus fertilizers for the production of their food – and generally fertilizers are often over-applied or applied when they cannot be effectively utilized by crops. Some 20% of nitrogen fertilizer is lost through surface runoff or leaching into groundwater. A significant proportion of nitrogen is also lost to the atmosphere via denitrification and ammonia volatilisation.

The effect of the enhanced mobilization of nutrients into coastal and marine ecosystems cause eutrophication, resulting in changes in species diversity, reduction in dissolved oxygen and associated fish kill, and increased prevalence or frequency of algal blooms leading to adverse impacts including mortality of benthic organism, collapse of fisheries and shellfish poisoning.

Global loss of ecosystem services due to by eutrophication of coastal waters caused by excess nutrients is estimated at USD 200 billion per year.

Worldwide, the number of coastal areas impacted by eutrophication caused by excess nutrients stands at over 500. Dead zones in the world's oceans have increased from 10 cases in 1960 to nearly 500 documented cases in 20108 (see Map 2: The world hypoxic and eutrophic coastal area).

Many of the world's freshwater lakes, streams, and reservoirs suffer from eutrophication – millions of people depend on wells for their water where nitrate levels are well above recommended levels.

More than 90% of the world's fisheries depend in one way or another on estuarine and near-shore habitats, which are becoming vulnerable due to expansion of hypoxic and dead zones

An estimated 90% of wastewater in developing countries is discharged untreated into waterways and coastal areas.

Nitrous oxide is a powerful greenhouse gas –estimated to be responsible on current levels for about 11% of the net anthropogenic global warming potential from such gases.

FAO predictions are that by 2030, global nitrous oxide (N_2O) emissions from fertilizer and manure application will increase by 35% to 60%.

The potential for global warming of one unit of N_2O is 296 times greater than a unit of CO_2.

Globally, synthetic fertilizer and agricultural crops account for 12% of total ammonia emissions.

Nutrients – a priority action area identified under the Global Programme of Action[5]

7. Considering the multi-dimensional impacts of excessive nutrients on human health and wellbeing and the natural environment, the governments adopting the Global Programme of Action (GPA) identified nutrients as one of the source category of the GPA. In doing so, they noted that the effect of the enhanced mobilization of nutrients results in changes in species diversity, excessive algal growth, reduction in dissolved oxygen and associated fish kill, and an increased prevalence and frequency of algal blooms. Through the GPA, the governments have committed to develop and put in place "appropriate cost-effective policy instruments, including regulatory measures, economic instruments and voluntary agreements, to control anthropogenic sources of nutrients…..(and) formulation and implementation of awareness and information campaigns for adoption of appropriate agricultural techniques, including balanced fertilization and ecological agriculture, to minimize nutrient losses from agricultural activities, and introduction of measures to reduce inputs of nutrients via atmospheric deposition from transportation, industrial plants and agriculture" (GPA 1995:50-51).

8. The governments reiterated their commitments to address nutrients when they met in Johannesburg in 2002 during the World Summit on Sustainable Development to review the progress in the implementation of the Agenda 21. The Johannesburg Plan of Implementation specifically called on all governments to "……advance implementation of the GPA and the Montreal Declaration,[6] with particular emphasis during the period 2002-2006 on municipal wastewater, the physical alterations and destruction of habitat, and **nutrients**….." (JPOI, 2002: Para 33). Again in 2006, through the Beijing Declaration 104 Governments and the European Commission resolved "**To devote additional effort, finance and support to address point and non-point source nutrients, including municipal, industrial and agricultural wastewater**, as major and increasing source categories directly affecting human health, well-being and the environment, including marine ecosystems and their associated watersheds" (Beijing Declaration, 2006, para 11, emphasis added).

Nutrient over-enrichment, eutrophication, dead zones and the coastal ecosystems

9. Nutrient over-enrichment of coastal waters and large marine ecosystems is an increasing problem worldwide. Key sources of nutrients include: agriculture - in particular through leaching, runoff and atmospheric emission from agricultural fields receiving inorganic fertilizers and manures from concentrated livestock operations and aquaculture, direct discharge of nutrients from large confined animal operations to water and air; wastewater discharge from sewage and industry, and fossil fuel emissions from energy, industry and transport and subsequent dispersion and deposition. These nutrients can enter coastal and marine ecosystems through the air, surface water and groundwater. It has been estimated that the global load of nitrogen to the coastal zone increased three fold between the 1970s and 1990s[7] and is expected to continue to rise[8].

10. As outlined in Diagram 1, increased load of nutrients, such as nitrogen and phosphorus, to fresh and marine surface waters can cause phytoplankton and macro algal blooms which can block light transmission and lead to the loss of subaquatic vegetation. This process is known as eutrophication. The two most acute symptoms of eutrophication are hypoxia (or oxygen depletion) and harmful algal blooms. The imbalance in nutrient ratios can change the benthic community structure by creating conditions that favour nuisance or toxic algae that can lead to fish kills and human illness through shellfish poisoning, death of marine mammals and shore birds.[9] Eventually, coral reefs can be damaged and species diversity can be reduced and lead to systems dominated by gelatinous organisms such as jellyfish. Globally, harmful algal blooms are considerably more widespread and frequent than they were a decade ago, a situation that is expected to further deteriorate by

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[5] The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) is an intergovernmental programme adopted by the governments in a meeting held in Washington DC, USA in 1995 (see www.gap.unep.org).

[6] Montreal Declaration adopted by the governments during the first intergovernmental review meeting of the GPA calls on "[…] United Nations Agencies and programmes and international financial institutions to incorporate, where appropriate, the objectives of the GPA into their respective work programmes, giving priority in the period 2002 – 2006 to addressing the impacts of sewage, physical alteration and destruction of habitants and <u>nutrients</u> on the marine environment, human health…"

[7] UNEP/GEF/LOICZ: 2006. The role of the coastal ocean in the disturbed and undisturbed nutrient and carbon cycles.

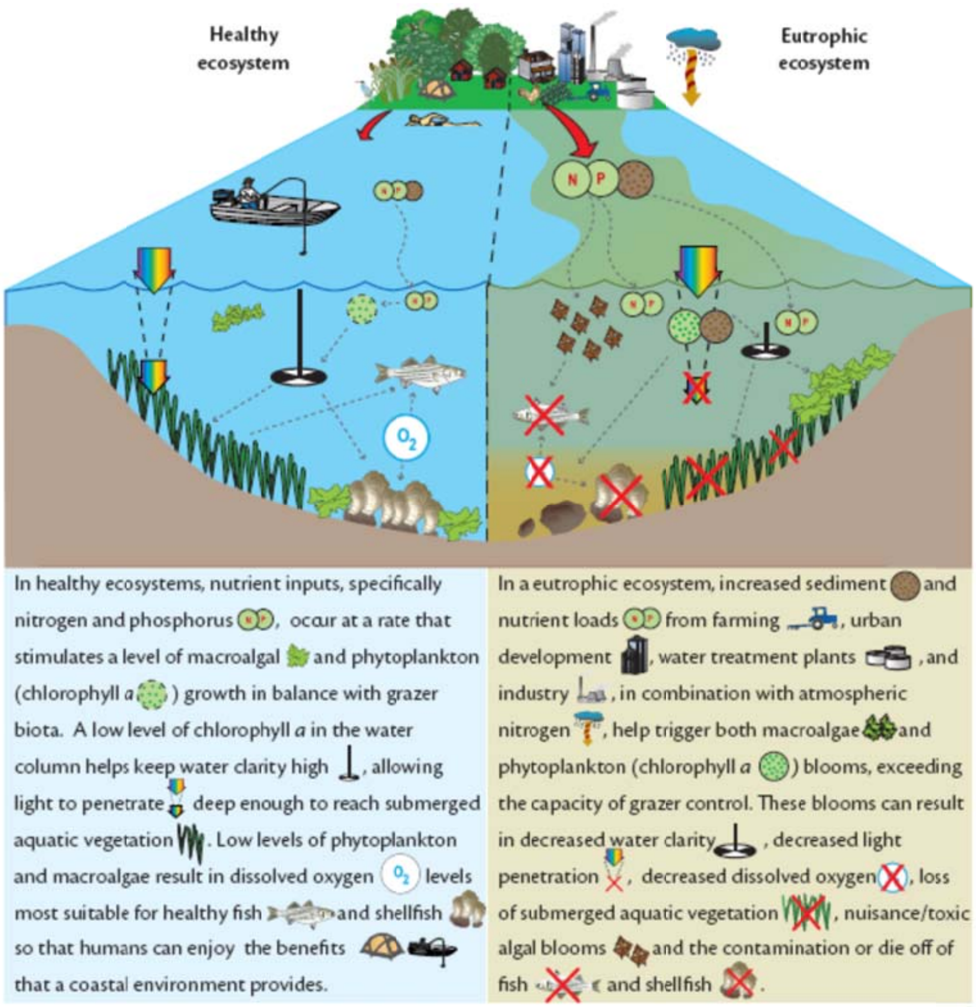
[8] UNEP/GPA: 2006. State of the Marine Environment.

[9] Anderson et al. 2002. Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition and Consequences. Estuaries 25(4b). quoted in WRI 2008:2.

2020,[10] if concerted efforts are not taken to monitor nutrient budgets and put into practice much more effective nutrient management strategies.

11. Human activity over the last 50 years has greatly increased the flux of nutrients through the landscape, nearly nine folds of nitrogen and more than tripled of phosphorus in the landscape (see figure 3). Land-based activities are the dominant source of nutrients and these can enter coastal ecosystems through different pathways including air, surface water and groundwater. It is however, important to note that before nutrients, such as nitrogen and phosphorus, reach the "coastal ecosystems, they pass through a variety of terrestrial and freshwater ecosystems, causing other environmental problems such as freshwater quality impairments, acid rain, the formation of greenhouse gases, a shift in community food webs, and a loss of biodiversity" (WRI 2008:2). The impacts of eutrophication on ecosystem health are clearly illustrated in Diagram 1.

Diagram 1: Conceptual diagram comparing a healthy system with no or low eutrophic conditions to an unhealthy system exhibiting eutrophic systems.

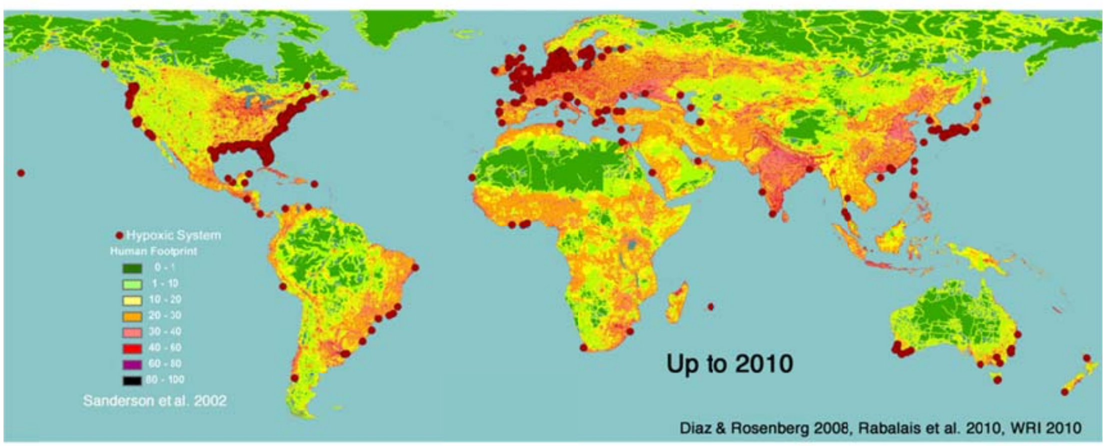


Source: Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks and J. Woerner. 2007. Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change, National Estuarine Eutrophication Assessment Update. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. 322 pp.

[10] GIWA: 2006. Challenges to International Waters Regional Assessments in a Global Perspective.

12. Eutrophication can lead to oxygen depletion (hypoxia) or 'dead' zones. These are caused when algae die, sink to the bottom and are digested by bacteria, in the process using up the available dissolved oxygen. After the 9 documented hypoxic zones in 1960, the number of hypoxic areas has doubled every decade. A panel of experts convened under the auspices of the World Resources Institute (WRI) in late 2007 identified 415 eutrophic and hypoxic coastal systems worldwide. Of these, 169 are documented hypoxic areas, 233 were areas of concern and 13 systems were in recovery[11]. Robert Diaz (2010) based on the analyses of data from the work of Diaz and Rosenberg (2008), Rabalais et al (2010) and WRI (2010) argued that there are nearly 500 documented hypoxic areas (see Map 2: World hypoxic and eutrophic coastal area). Oxygen depleted zones are present not only in enclosed seas, such as the Baltic Sea and the Black Sea, but also in large coastal areas which have internationally important fisheries. Eutrophication is likely to intensify in response to the increased application of fertilizers, growth in confined animal production as dietary patterns change worldwide, aquaculture industry, increasing quantities of human sewage, the generation of nitrogen from fossil fuel combustion, and potentially as a result of global warming (GIWA, 2006). Indeed, in UNEP published Global Environmental Outlook – 4 (GEO-4), summary observations on "system perspectives: thresholds, switches, tipping points and inertia" noted that a number of environmental thresholds have been crossed due to sustained human activities including: collapse of fisheries, eutrophication and deprivation of oxygen (hypoxia) in aquatic systems (UNEP 2007:402). The WRI report also notes that data on the extent and prevalence of eutrophication does not exist or is not available in some regions, notably in Asia, Africa, South America and the Caribbean regions, which strongly suggests that the number of eutrophic and hypoxic coastal systems could actually be much higher (op.cit. 2008:4).

Map 2: World Hypoxic and Eutrophic Coastal Area (Diaz 2010)[12]



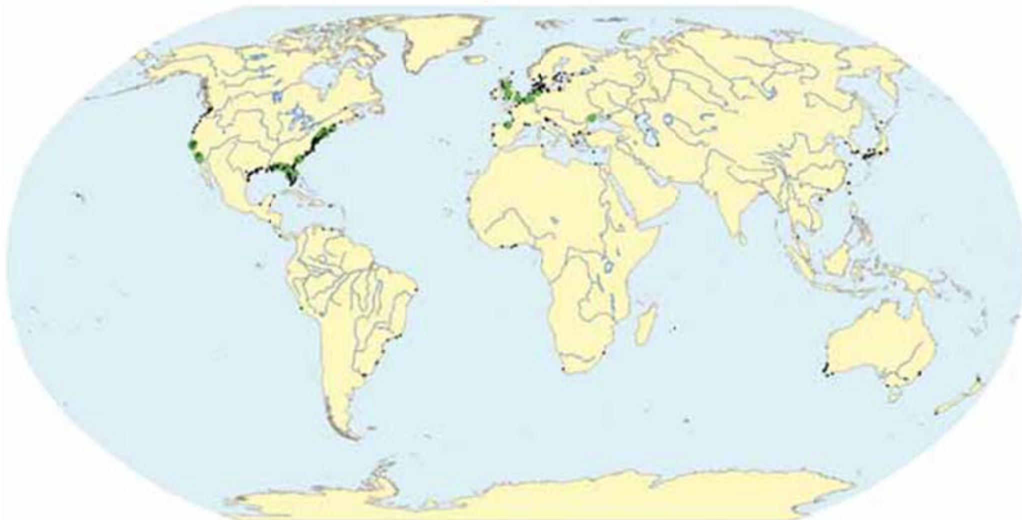
13. The Scientific and Technical Advisory Panel (STAP)[13] administered by UNEP advises the Global Environment Facility, and in one of its recent advisory documents, noted that while "the causal relationship between eutrophication and the occurrence of hypoxia is well established, …. the relationship linking nutrient reduction to reduced eutrophication to reduced hypoxia often is non-linear, especially in large systems and differs from system to system". Based on detailed analyses of various systems, the STAP study reported that

[11] World Resources Institute: 2008. Policy Note on Water Quality: Eutrophication and Hypoxia, March.
[12] Robert Diaz (2010). Current Situation of the Hypoxic Zones in the World and Nutrient Reduction. A progress report "From the Rivers to the Gulf of Mexico, Towards an Ecosystem Management Approach" Presentation made during the Regional International Forum. in Mexico City, September 27-28, 2010

[13] STAP: 2011. Hypoxia and Nutrient Reduction in the Coastal Zone. Advice for Prevention, Remediation and Research. A STAP advisory document, September.

for smaller systems, reductions in nutrient loadings led to reduced eutrophication and hypoxia and encouragingly, that the system recovery process could occur within 5 to 10 years. The STAP document was based on the analyses of 50 case studies by Rabalais et al (2010) and clearly showed that there are signs of improved oxygen conditions in aquatic systems worldwide due to improved management of nutrients (see Map 3). The study, therefore, argued that "monitoring and research specific to each system and its sources of nutrient pollution will be required in order to understand and adapt preventive and remediation actions" and concludes that the drivers of eutrophication need to be reduced (STAP 2011:24-25).

Map 3: Location of systems that have recovered from hypoxia (green circles), primarily through reduced nutrient loads, and black dots are systems that remain hypoxic Rabalais *et al.*, 2010, quoted in STAP 2011)



Nitrogen and climate change[14]

14. The nitrogen and carbon cycles are closely linked and both are changing rapidly. In the last six decades, human production of reactive nitrogen has outstripped production from all natural terrestrial systems. At the same time, rapid increases in atmospheric greenhouse gases have led to climate change. Changes in the nitrogen-cycle and greenhouse gas emissions have the same drivers: population growth, changes in human diets, increased demand for energy, food, livestock feed and fiber, and land-use change.

15. The massive alteration of the nitrogen cycle due to human activity affects climate, food security, energy security, human health and ecosystem services. The long-term consequences of huge changes to the nitrogen cycle are yet to be fully realized, but have been largely ignored in global environmental assessments and climate policy. The latest research suggests international nitrogen management will be part of the solution to tackling climate change. The question is, how does artificial reactive nitrogen production exacerbate the climate-change problem? And how does reactive nitrogen alter mitigation and adaptation options to address climate change?

16. There are several nitrogen management options that affect climate directly. In many countries, more nitrogen is commonly used for crop production than is required, hence there is substantial wastage. Improving nitrogen use efficiency leads to lower atmospheric emissions of nitrous oxide (N_2O), a strong greenhouse gas, which means a

[14] This section is written based on "Interactions of reactive nitrogen with climate change and opportunities for integrated management strategies". Draft report prepared by Jan Willem Erisman together with the UNECE Taskforce on Reactive Nitrogen (TFRN). September 2010.

positive effect for the climate. Other options have a negative effect on climate (net-increase in greenhouse gas emissions) but positive benefits for human health and ecosystem services, for example, reducing atmospheric emissions of nitrogen oxide and/or ammonia. A decrease in the atmospheric concentration of these chemicals leads to a decrease in particle concentrations in the atmosphere. Small particles, or aerosols, in the atmosphere have a complex effect on climate and the Earth's radiative balance, but overall they tend to cool the planet. Decreasing the number of these particles in the atmosphere could lead to more warming, though we would see an improvement in respiratory problems and other health benefits.

17. Furthermore, reducing atmospheric reactive nitrogen emissions decreases the amount of reactive nitrogen deposited on the land and oceans, thus protecting biodiversity. But, less nitrogen in these systems weakens these carbon sinks. There is a delicate balance between climate benefits of nitrogen management and the co-benefits for human health, ecosystem services and food production to feed the world.

18. A preliminary assessment suggests that the human perturbation of the N-cycle has a net cooling (positive) effect in the short term, mostly due to the effect of nitrogen on carbon sequestration in ecosystems and the effect of direct aerosol formation. But there are negative effects on human health and ecosystem services. However, these estimates are uncertain and the range often includes a net effect of zero. Moreover, the long-term effects of N_2O on radiative forcing may outlast the effects of carbon sequestration in forests and soils, which are subject to disturbance and saturation. The present knowledge does not allow quantifying the full interactions between changes in nitrogen emissions and climate change.

19. There are large regional differences throughout the world in all aspects of nutrient management and nutrient use efficiency by agricultural systems. Developed countries have excess nitrogen and use relatively large quantities of nitrogen fertilizer in agriculture. They could limit reactive nitrogen losses to the environment with a minimal effect on climate by expanding the adopting of fertilizer best management practices (such as the 4R global nutrient stewardship framework[15]). Large regions of the world, particularly in the developing countries, however, are nitrogen poor. Without access to reactive nitrogen in the form of fertilizer, food production is limited. In these cases, the effect on climate is deleterious because of erosion, soil degradation, limited carbon sequestration and deforestation. It is expected that demand for more food production will lead to farmers using more fertilizers in developing regions, initially increasing carbon sequestration with a positive effect on climate. But when application rates increase and nitrogen losses rise then the effect on climate will become negative.

20. The known links between the nitrogen and carbon cycles are well established. However, our skill in incorporating carbon - nitrogen interactions into global biogeochemical models is still poor, and there is an urgent need to undertake research to fill-in the knowledge gaps. While research for generation of knowledge may continue, based on available science, global nitrogen policies today and in near future should focus on use of current scientific knowledge to identify win-win that address climate change and other areas affected by nitrogen such as water quality. Policies need to assess the impact of nitrogen emissions from all aspects of fossil fuel burning, fertilizer production and use and the effects of growth in intensive animal agricultural productions systems in emerging economies. Furthermore, excess nitrogen reduces some ecosystems' ability to contribute to climate-change mitigation and adaptation. This is particularly true of marine and coastal systems.

Nutrients and Energy Security

21. The growth in the amount of nutrients in the environment, specifically nitrogen, has also been driven in large part by the demand for energy derived from burning of fossil fuels. As in the case of food security, attempts to address excess nutrients will also need to meet the concerns of countries over energy security.

22. Indeed, there is a close relationship between fossil fuel use and nitrogen production. More fossil fuel combustion for transportation, and industrial and energy production results in the formation of nitrogen oxide

[15] http://www.sustainablecropnutrition.org; www.nutrientstewardship.com

(NOx), which apart from contributing directly to the range of environmental problems previously described, also constitutes a powerful greenhouse gas. And historically, as the industrial revolution progressed, the very availability of fossil fuels helped to trigger and enable the amount of industrial production of synthetic nitrogen to be greatly accelerated. Carbon dioxide resulting from the production and consumption of fertilizer is an important component of some countries' overall greenhouse gas emissions.

23. Finally, the shift towards renewable energy sources has led to the additional use of fertilizers for the production of crops and biomass for bio-energy and bio-fuel production. Currently, bio-energy contributes 10% to global energy use, but as present climate and energy policies have tended to stimulate bio-fuel production, the world's greater reliance on bio-fuels will likely lead to increased fertilizer use and create demands for the production of nitrogen to grow, depending on which soils and crops are used and the extent of nitrogen use efficiencies in food and bio-fuel production.

24. There is, moreover, growing evidence that the amount of reactive nitrogen in the environment is playing an important role in relation to climate change (as discussed in the previous section) and that there are important win - win economic benefits from investing in establishing limits on emissions of N_2O and increasing the efficiency of nutrient use by agriculture and other sectors. This should eventually allow us to reduce dependency on fossil fuels and lead towards a lower carbon society.

Nitrogen and phosphorus cycles and the planetary boundaries[16]

25. Agriculture (both intensive and extensive) generates environmental pollution, including large-scale nitrogen and phosphorus-induced environmental change. On a global scale, the additional amounts of nitrogen and phosphorus used by humans to produce food and in others sectors are now so large that they significantly perturb the global cycles of these two important elements. Human activities, primarily the manufacture of fertilizer for food production, the cultivation of leguminous crops and industrial livestock production convert around 120 million tonnes of nitrogen from the atmosphere per year into reactive forms — which is more than the combined effects from all Earth's terrestrial nitrogen fixation processes. Much of this new reactive nitrogen ends up in the environment, polluting inland waters and coastal zones, accumulating in terrestrial systems and adding a number of gases to the atmosphere that impact the world's climate

26. Nutrient generated impacts stimulated academic discussions and prompted the formulation of a 'planetary boundary' for nitrogen and phosphorus flows, which Rockstrom et. al. (2009) proposed to keep together as one boundary given their close interactions with other Earth-system processes.

27. According to Rockstrom et. al. (2009), setting a 'planetary boundary' for human modification of the nitrogen cycle is not straightforward. Therefore, they have defined the boundary by considering the human fixation of atmospheric nitrogen as a giant 'valve' that controls a massive flow of new reactive nitrogen into the Earth's fragile ecosystems. As a first approximation the authors suggested that this valve should contain the flow of new reactive nitrogen into the global ecosystems to 25% of its current value, or about 35 million tonnes of nitrogen per year. Given the implications of trying to reach this target, the study noted that much more research and synthesis of information is required to determine a more informed boundary. The Diagram -2 below shows that due to human interference the nitrogen cycle has gone beyond appropriate global limits.

28. Unlike nitrogen, phosphorus is a fossil mineral that accumulates as a result of geological processes. It is mined from rock and its uses range from fertilizers to toothpaste. Some 20 million tonnes of phosphorus are mined every year and around 8.5 to 9.5 million tonnes, more than 8 times the natural influx eventually is discharged into the world's oceans.

29. Records of Earth history show that large-scale ocean anoxic events occur when critical thresholds of phosphorus inflow to the oceans are crossed. This potentially explains past mass extinctions of marine life. Modeling suggests that a sustained increase of phosphorus discharge into the oceans which exceeded 20% of natural background weathering was enough to induce past anoxic events in our oceans. Tentative modeling estimates suggest that if there is a greater than tenfold increase in phosphorus flowing into the oceans (compared with pre-industrial levels), then anoxic oceanic events will become more likely within 1,000 years. Despite the large uncertainties involved, the state of current science and the present observations of abrupt

[16] This section is an abridged version of "Planetary Boundaries: exploring the safe operating space for humanity" written by Johan Rockstrom and colleagues. Nature, Vol. 461, September 2009.

phosphorus-induced regional anoxic events indicate that no more than 11 million tonnes of phosphorus per year should be allowed to flow into the oceans — ten times the natural background rate. The authors, therefore, note that this boundary level will allow humanity to safely steer away from the risk of ocean anoxic events for more than 1,000 years, acknowledging that current levels already exceed critical thresholds for many estuaries and freshwater systems.

Planetary Boundaries

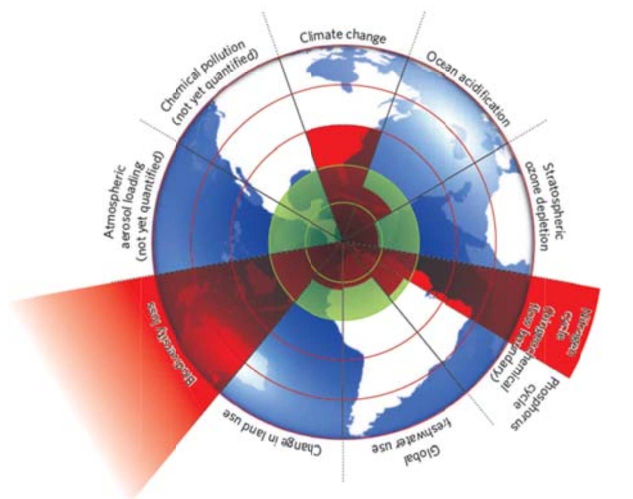


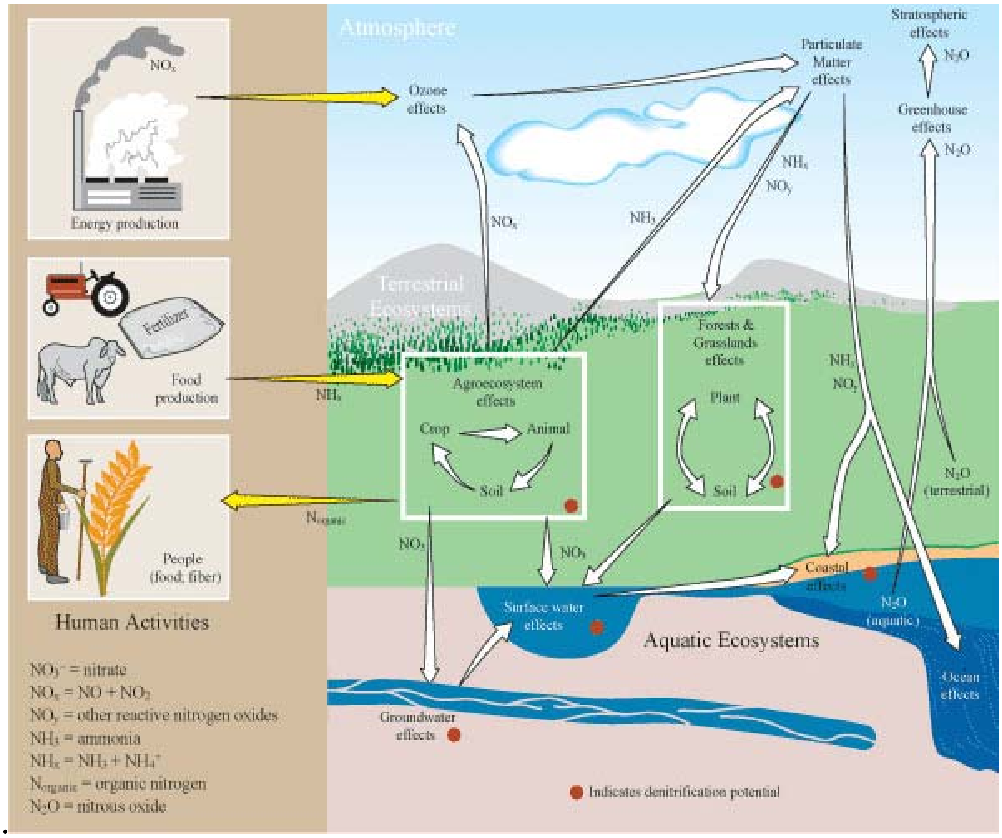
Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

Source: Johan Rockström et al, in The Nature 24 September 2009

Nitrogen cascade, cost and complexity

30. Reactive nitrogen is particularly challenging. A single molecule of reactive nitrogen may move successively through the environment in a variety of ways causing a succession of harmful impacts – often referred to as **the nitrogen cascade** (see Diagram 3 below). In the air, this means more ozone causing respiratory ailments and vegetation damage. From the air, nitrogen can be deposited on land surfaces, acidifying buildings, soils and water bodies, and fertilizing trees and grasslands, creating nutrient imbalances and changing biodiversity. On reaching coastal zones it can harm fish stocks and biodiversity. Finally, part of the molecule gets converted to nitrous oxide, contributing to greenhouse gases and ozone depletion. This illustrates the need for integrated planning and management approaches, which address multiple impacts of nutrients on Earth and a better understanding of the trade-offs and synergies that arise between sustaining ecosystem services and ensuring human well-being.

Diagram 3: The nitrogen cascade



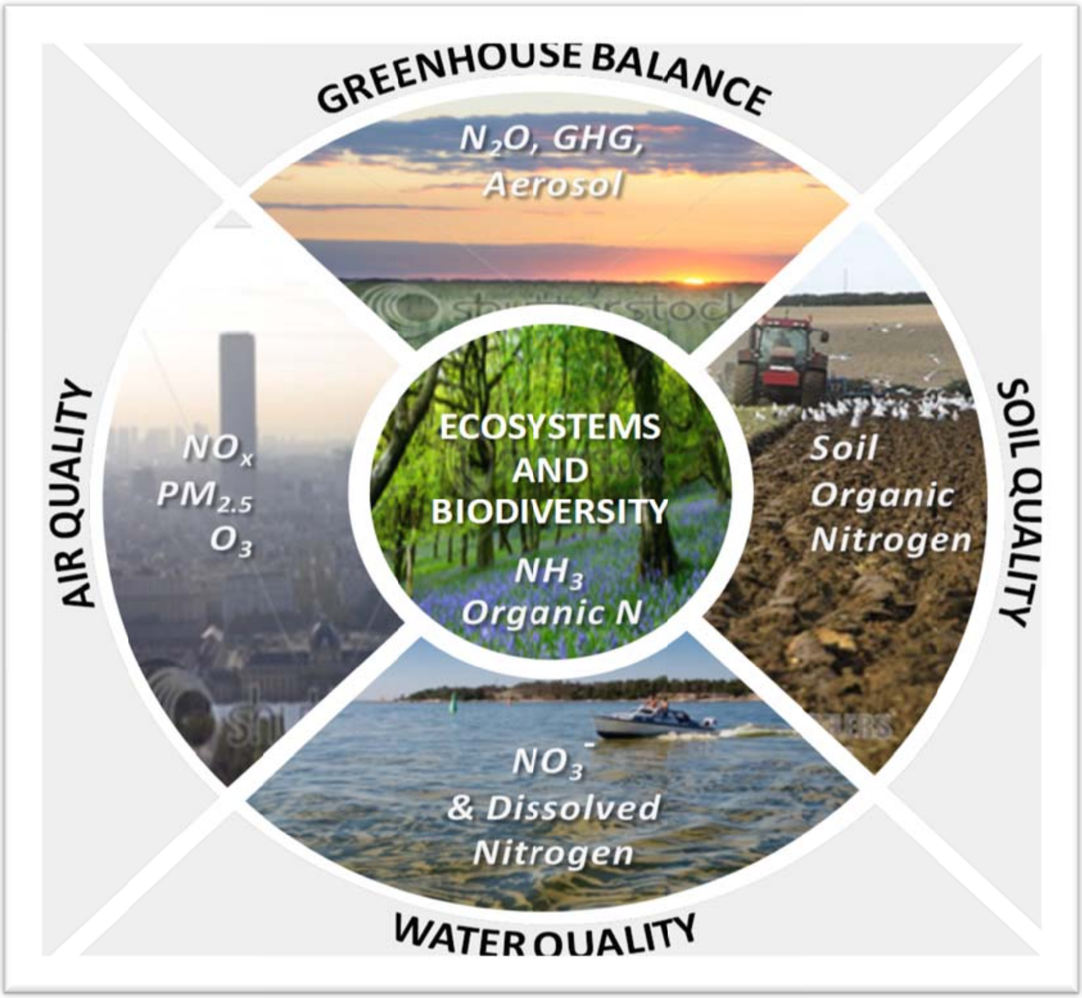
Source: adaptation from Galloway and others 2003 redrawn by Robert Smith

Addressing the nutrient challenge – the key question and what we need to do

31. Environmental problems in the coastal oceans associated with nitrogen pollution are global in scope and are likely to magnify as the population increases and use of inorganic fertilizers, animal manures and other organic by-products of society, and fossil fuel continues to intensify. The European Nitrogen Assessment (ENA) was carried out by a group of scientists (Sutton et al 2011)[17] as a contribution to the work of the Task Force on Reactive Nitrogen (TFRN). The ENA supported the long-term goals of the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and reported five key societal threats from excess reactive nitrogen. These are water quality, air quality, greenhouse gas balance, ecosystems and biodiversity, and soil quality. In short this is referred to as “WAGES” and the Diagram 4 below illustrates the threats of each five.

[17] Mark Sutton et al.: 2011. The European Nitrogen Assessment. Sources, Effects and Policy Perspectives. Cambridge University Press.

Diagram 4: Five key societal threats of excess reactive nitrogen



32. The main message of the European Nitrogen Assessment report is "too much nitrogen harms the environment and the economy". The report clearly demonstrated that inappropriate or overuse of nitrogen as fertilizer has considerable adverse effects on the environment and human health. Cost benefit analysis shows that for Europe overall cost of nitrogen losses is in the range of Euro 70 to 320 billion per year which overweigh the direct economic benefits of nitrogen in agriculture. The highest societal costs are associated with loss of air quality and water quality, linked to impacts on ecosystems and especially, on human health. The report identified a package of 7 key actions for overall management of European nitrogen cycle. **Three proposed actions directly relate to Agriculture** - improving nitrogen use efficiency in crop production; improving nitrogen use efficiency in animal production and increasing the fertilizer nitrogen equivalent value of animal manure; **one for Transport and Industry-** low-emission combustion/energy-efficient systems and use of alternative energy sources with less emission; **one related to Wastewater treatment** - recycling nitrogen and phosphorus from wastewater systems utilizing new sewage management technologies and **two actions are related to Societal consumption patterns** - energy and transport savings, and lowering the human consumption of animal protein (ibid. xxiv –xxxii).

33. In this backdrop, the key question that needs to be answered is **how can we promote effective nutrient management worldwide, minimising negative impacts on the environment and human health, while maximising their contribution to global sustainable development and poverty reduction?'** It is argued

that if the nutrient challenge is to be met, it will be important to show that improved NUE with an increase in productivity is an essential part of meeting sustainable food security, including in areas with an overall shortage of nutrients, and sustenance of the natural environment and the ecosystems services which are vital to enhance human wellbeing.

The Global Partnership on Nutrient Management (GPNM) – a response to the challenge

34. The Global Partnership on Nutrient Management (GPNM) has been launched to answering this challenge. The GPNM is a global partnership of governments, scientists, policy makers, private sector, NGOs and international organisations.[18]

35. To date, the Governments of the Netherlands, USA (US Department of Agriculture, US National Oceanic and Atmospheric Administration), Italy, Indonesia and Thailand; the European Commission, the Task Force on Reactive Nitrogen under the Convention on Long Range Trans-boundary Air Pollution of the UNECE and UK-China Sustainable Agriculture Innovation Network (SAIN); private sector institutions such as the International Fertilizer Industry Association (IFA), the World Phosphate Institute, Nagarjuna Fertilizers and Chemicals Ltd. India; UN agencies namely IOC/UNESCO, UN-FAO, UN-HABITAT, UNDP; Academic and Research institutions such as International Nitrogen Initiative (INI), International Geosphere-Biosphere Programme (IGBP), The Scientific Committee on Problems of the Environment (SCOPE), The Netherlands Energy Research Centre, Netherlands Environmental Assessment Agency, Department of Earth Sciences and Geochemistry, Faculty of Geosciences, Utrecht University; Vrije University, Amsterdam; Institute for Ocean Management, Anna University, India; Indian Nitrogen Group; China Agricultural University; Department of Marine Science, Chulalongkorn University, Thailand, Cyprus University of Technology; and NGOs, namely The Nature Conservancy and Global Environment and Technology Foundation, have already joined the GPNM.

36. The Partnership recognised the need for strategic advocacy and co-operation at the global level in order to communicate and trigger productive discussion not only on the complexity of the nutrient challenge but also on the opportunities for cost effective policy and investment interventions by countries. The GPNM, among others, aims to bridge the problem of lack of information and assessment capacity in various regions of the world, and enhancing the capacities of various stakeholders to design and implement effective management policies to address the growing global problem of nutrient over-enrichment.

37. The GPNM foresees its role as leading the positioning of nutrient issues as a key part of the international sustainable development agenda – ultimately the global challenge of nutrient management can be seen as one of ‘sustainable consumption and production’ of nutrients. The GPNM through its participation and holding of special sessions during the deliberations of the United Nations Commission on Sustainable Development (UN-CSD) is building a global advocacy platform to ensure synergies among the many actors engaged in the global and regional nutrient assessments to promote integrated assessment, and give substance to costs of inaction and opportunities for win - win investments.

38. The GPNM strongly believes that nutrient related concerns, opportunities and actions we face today must be embedded into the work of various agencies and fora, and therefore the emphasis is on communication focused on describing the challenges of nutrient management - from food security to dead zones in the world oceans- and elucidating how integrated assessment, best practices and stakeholder engagement can facilitate better sustainable nutrient production and use.

39. Given the complexity of global nutrient problems, action must involve many industrial and social sectors. It is also important to recognize that cause-effect outcomes are embedded in societal values. For example, in coastal regions, which are some of the most impacted by nutrients today, reducing nutrient inputs would

[18] The GPNM was launched during the 17th session of the United Nations Commission of Sustainable Development in the UN Headquarter in New York, USA.

require tackling subsidy allocations in fertilizer, agricultural products, fishing enterprises, as well as municipal sanitation works.

40. The use and discharge of nutrients from agriculture is a major challenge. Fertilizer best management practices emphasizing the “4R” –right source, right rate at the right time and the right place regarding nutrient use, and conservation agriculture that involves minimal soil disturbance, permanent soil cover and crop rotations, are some agricultural approaches that may assist in responding to the challenge. Agriculture can also recycle nutrients from other sources e.g., manures and wastewaters from confined animal operations, organic waste and wastewater from cities and industries that can be re-used for production of agro-energy crops. Farmer incentives and participation will be critical in implementing new and more nutrient-efficient agricultural practices. For the GPNM, proponents of conservation agriculture are potential allies of the government agencies and their many partners who wish to reduce nutrient discharges to inland and coastal waters.

41. In general, economic analysis of nutrient reduction options has proven challenging due to a lack of baseline data. Also, options may need to trade off cheaper but more challenging solutions, such as increasing nutrient use efficiency, thereby reducing fertilizer use, against options that are initially more costly but, over time, may be more cost-effective, such as the construction of artificial wetlands.

42. The Foundations for Effective Nutrient Management, a product of the GPNM (2010)[19], scope out the challenge, from food security to dead zones to decaying deltas, and identify the potential for better assessment and information, and conclude by charting how strategic action by countries – the communication and mainstreaming of key messages and best practices, prompted and supported by partnerships, stakeholder engagement and integrated approaches - can lead to effective nutrient management and the benefits this will bring to meeting the key global challenges of food security and a healthy and sustainable environment.

43. The GPNM seeks to draw attention to the need for more nutrients in areas of soil mining in order to meet the growing crop demands for higher levels of food production in countries with rapidly growing population and inadequate resources for agriculture. In so doing, it promotes the fundamentally important message, and delineates the means to achieve it: that in moving to higher levels of food production, countries need to build in and embed the application of best practices and approaches to crop and soil management with an emphasis on efficient use of nutrients. In this way, farmers can benefit directly in cost savings, while countries can avoid costly adverse impacts to their natural resources from excess nutrients, including harm to their inland and coastal fisheries, which are also critical to food security. There are real win - win investment and development opportunities if these approaches are taken and fully integrated with other aspects of socio-economic development.

44. This message is consistent with the work of the Food and Agricultural Organization of the United Nations (FAO), the International Fund for Agricultural Development (IFAD) and the International Fertilizer Industry Association (IFA). They have shown that it is possible to engage large numbers of farmers in identifying and applying site specific solutions involving the use of simple and improved agricultural technologies to make significant headway in addressing the problems of improved crop yields and food security.

45. There is now a general consensus and widespread awareness that an ecosystem approach must underpin the intensification of crop production as we struggle to meet future food demands worldwide. This calls for substantial changes in the food production system, including defining approaches to sustainable intensification that can simultaneously raise yields, increase efficiency in the use of inputs and reduce the negative environmental effects associated with many food production systems. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) also called for a shift from current farming practices to sustainable agriculture systems capable of providing both significant productivity increases and enhanced ecosystem services (cf. FAO 2011).

[19] GPNM/UNEP 2010. Building the Foundations for Sustainable Nutrient Management. http://www.unep.org/pdf/Building_the_foundations-2.pdf

Conclusions

46. In conclusion it is important to reiterate **that managing nutrients efficiently has global relevance to food and energy security, water quality and availability, biodiversity and fisheries, and climate change.** To meet the nutrient challenge we need to show that greater efficiency in fertilizer use by all sectors, including crop and animal production systems, is an important part of ensuring sustainable food security, including in areas where there is overall shortage of nutrients. Furthermore, we need to find a way of simultaneously addressing poverty, climate change and the depletion of natural resources.

47. Too little or too much of nutrients – both have significant and long-standing impacts on human health and wellbeing and the quality of our environment. The problems associated with nutrient management, as illustrated above, have high economic costs, are often complex and are not amenable to single solutions. The questions therefore are, who pays for the costs for these human wellbeing and environmental problems and how to apportion such cost among those engaged in the management of nutrients for agriculture and others sectors. Since the governments have a pivotal role in supporting sustainable production systems to ensure adequate supply of food for a growing global population while protecting the environment, the key responsibility lies with them. However, there are also formal and informal "rules" that govern and organize social behaviour and relationships and the structures of social and economic institutions that influence the use of means of production including the endowment of natural capital, and the way that an economy uses this endowment. This in turn defines the 'social order' and establishes a set of stable economic institutions, that have profound influences on how production is organised and all societal inputs are combined and used (cf. Edward Barbier: 2011:237-8).[20]

48. Viewed from this perspective, it can be argued that in meeting the challenge of food security, environmental quality, human health and sustainable development, both State and non-state actors need to work in partnership. It is important that the governments and other stakeholders agree on a NUE target e.g., at least 20% improvement from the current baseline over the next five years (2012-2016).[21] The GPNM as a multi-stakeholder platform provides the space where governments and other stakeholders can engage in dialogue and forge co-operative partnership across the variety of international and regional fora and with many agencies dealing with nutrients. These should include setting up NUE targets, identifying the extent of assessment work needed to verify targets and being achieved, and launching valuation studies to estimate the impacts of nutrient over-enrichment and/or deficit for society. This will lead to a better understanding of the costs and benefits of changing practices and broader agreement on the new policy approaches needed to reverse the current inefficient practices of nutrient use.

49. Finally, it is reemphasized that developing effective policies to manage nutrients for food security and environmental sustainability, economic and environmental models need to be integrated. Each country, and the boarder global community, must devise appropriate economic tools to promote and facilitate changes in the use and production of nutrients. what is needed, as Allen Good and Perrin Beatty argued in their article "Fertilizing Nature: A Tragedy of Excess in the Commons"[22], is a way to measure the environmental and economic optimal for nutrient application taking into account the price of applied nutrients plus the cost of nutrient lost to the environment.

[20] Edward Barbier 2011. The policy challenges for green economy and sustainable economic development. In Natural Resources Forum, A United Nations Sustainable Development Journal. Special issue on green economy and sustainable development. Vol 35, no 3. August.
[21] It is worth noting that "increased fertilizer use efficiency could meet the projected 38% increase in global cereal demand by 2025 with a 25% decrease in nitrogen fertilizer application" (GPNM/UNEP 2010:6. Building the Foundations for Sustainable Nutrient Management. http://www.unep.org/pdf/Building_the_foundations-2.pdf)
[22] Allen G. Good and Perrin H. Beatty 2011. Fertilizing Nature: A Tragedy of Excess in the Commons. PLoS Biology, (www.plosbiology.org), Volume 9, Issue 8, August.