Environmental and Health Impacts of Pesticides and Fertilizers and Ways of Minimizing Them

Envisioning A Chemical-Safe World

Chapter 11 of 12

Current fertilizer risk reduction and risk management

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About

In December 2017, Resolution 4 of the 3rd Session of the United Nations Environment Assembly (UNEA 3) requested "the Executive Director to present a report on the environmental and health impacts of pesticides and fertilizers and ways of minimizing them, given the lack of data in that regard, in collaboration with the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO) and other relevant organizations by the fifth session of the United Nations Environment Assembly". In response to this request, UNEP published a *Synthesis Report on the Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them*[1] in February 2022 (United Nations Environment Programme [UNEP] 2022).

The overall goal of the synthesis report is to provide the information base to enable other advocacy actions to be taken by stakeholders to minimize the adverse impacts of pesticides and fertilizers. Specific objectives of the synthesis report are to:

- Update understanding of current pesticide and fertilizer use practices;
- Present major environmental and health effects of pesticides and fertilizers, during their life cycle, and identify key knowledge gaps;
- Review current management practices, legislation and policies aimed at reducing risks in the context of the global chemicals, environmental and health agenda;
- Identify opportunities to minimize environmental and health impacts, including proven and innovative approaches.

This chapter on "Current fertilizer risk reduction and risk management" is the 11th in a series of 12 chapters that make up a comprehensive compilation of scientific information. The chapters were developed to both inform and further elaborate on the information provided in the synthesis report. Please note that the disclaimers and copyright from the synthesis report apply.

1 The Synthesis report is available at https://www.unep.org/resources/report/environmental-and-health-impacts-pesticides-and-fertilizers-and-ways-minimizing.

Current fertilizer risk reduction and risk management

11

11.1 Overview

The content of this chapter is guided by: information compiled in the previous chapters (Chapters 7, 8, 9, and 10); contributions made by experts during a physical meeting of experts held in Geneva, Switzerland, in November 2019; a survey on challenges and opportunities for minimizing risks carried out in 2020; and the published literature. Information from previous chapters and information obtained from experts was used to confirm/identify measures for inclusion in the report. The published literature provides evidence concerning measures that have worked or not worked.

International conventions address fertilizer use indirectly. Their effectiveness in this regard remains undocumented. Furthermore, these conventions mainly address a specific issue while fertilizer use is associated with multiple issues. International conventions, as well as international partnerships that address fertilizer distribution and use, can provide an opportunity or platform for global discussions on sustainable fertilizer use.

International partnerships and initiatives addressing fertilizer distribution and use, such as the Intergovernmental Technical Panel on Soils of the Global Soil Partnership (GSP) (FAO 2019) and the International Nitrogen Management System (INMS) project (INMS 2021), have successfully provided scientific input to international decisions and outputs.

In many cases international conventions and regional agreements form a basis for measures taken at national level. Moreover, international and regional trade agreements have the potential to influence members to use fertilizer responsibly. [Chapter 11.2.1]

Regional agreements on fertilizers are more advanced in developed countries with shared markets (e.g., in the European Union), as are regional agreements on pollution, especially in the case of shared water bodies (e.g., in Europe and North America). Harmonization and implementation of regional fertilizer policies are hampered by a number of factors, including national interests and differences among stakeholders, and are yet to take off in some regions (e.g., Asia and Africa). [Chapter 11.2.1]

Many countries lack policies dedicated to fertilizers or there are gaps in their policies, their policies are fragmented, or other policies conflict with fertilizer policies. Developing countries are the worst performing. Many have rudimentary regulatory frameworks. Constraints on policy development include inadequate scientific evidence, inadequate funding and inadequate staff capacity. Implementation of regulations

is hampered by inadequate staff, inadequate laboratory facilities, lack of funding, the complexity of the problem of pollution from fertilizers, and overlapping mandates among ministries. [Chapter 11.2.1]

Many developing countries subsidize fertilizer, as food security is a key priority. Potential drawbacks of subsidies include an unbalanced supply of nutrients to the soil, inefficient fertilizer use, pressure on national budgets, and interference with the market. Switching to "smart subsidies" has improved their success. Subsidization of technologies has been proposed.

Few countries have environmentally related fertilizer taxes. Taxes have failed to address pollution, partly because they are often designed to raise revenue rather than to encourage sustainable fertilizer use. In addition, they are costly to enforce, and price changes have little or no effect on demand. [Chapter 11.2.2]

The private sector (fertilizer producers and distributors) has continued to promote best practices, for example through generating and promoting customized fertilizer products and participating in knowledge development and dissemination.

Educating and training knowledge disseminators and farmers encourages the adoption of best practices. Knowledge dissemination is sometimes hampered by lack of updated curricula on environmental issues in education programmes, a low and declining number of agricultural students and extension staff (especially in developing countries), reduced funding, weak research-extension-farmers links, and lack of harmonized messages. Non-traditional knowledge disseminators increasingly play an important role in knowledge dissemination.

Use of information and communications technology (ICT) in agriculture has contributed to an increase in the number of young farmers. It could also attract students to agriculture. Youth entering the agriculture sector bring in ICT expertise and cheaper communication technologies.

In many countries, fertilizer recommendations are not based on scientific evidence. Knowledge gaps with regard to adverse impacts of fertilizer use are a strong indication that recommendations do not usually take such impacts into consideration.

In some cases the public is not aware of the impact of fertilizer use or is misinformed. An informed public can make environmentally sound decisions on food choices and participate effectively in environmental conversations. However, actions by the public may not be effective due to lack of interest – or lack of coordination and funding – while laws may not support public participation. [Chapter 11.2.3]

Research is needed to address the large data gaps in the body of knowledge about fertilizer. However, such research is constrained by the decline in the number and funding of researchers, together with lack of coordination and collaboration. Research outputs are not always freely available to the public. Use of open science can improve the reliability of research and increase the number of research outputs. [Chapter 11.2.4]

In general, risk reduction and management require a combination of measures for success: "An efficient and effective policy approach to risk management in agriculture must take into account the interactions and trade-offs between different risks, on-farm strategies, and government policies" (Organisation for Economic Co-operation and Development [OECD] 2018, p. 1). While harmonization of policies at national level improves chances of success, harmonization at regional or even global level can improve these chances further. In the case of some environmental issues (e.g., nitrogen pollution), holistic approaches are likely to be more effective than fragmented ones. Improving efficiencies in the food system will make greater contributions to reducing the negative impact of fertilizer use than improving food production alone.

Actions that can contribute to reduced risks from fertilizer use include strengthening governance of the production, trade and use of fertilizers; strengthening the monitoring of fertilizers' use and effects; and providing support to R&D and extension services. [Chapter 11.3]

Bringing together nitrogen policies, which are currently fragmented among different environmental domains, would increase efficiencies and reduce trade-offs. Joint discussions on policies/initiatives for nitrogen and for phosphorus would potentially improve the efficiency of policies addressing both nutrients.

Sustainable nutrient management requires not only improving fertilizer use practices and technologies, but also making dietary changes towards more plant-based diets and reducing food loss and waste – thus contributing to a more efficient "from industry-to-farm-to-fork" fertilizer chain.

11.2 Assessing current risk reduction

11.2.1 Regulatory measures

International conventions and regional agreements are frequently a basis for measures taken at national level, including fertilizer evaluation, registration and labelling as well as control, enforcement and monitoring (Table 11.2-1). Measures at all levels of decision-making should be based on scientific evidence and the precautionary principle.

International conventions, voluntary international instruments, and partnerships

International conventions do not address fertilizer use directly, but several of them address fertilizer use indirectly. Their effectiveness in reducing the risks of fertilizer use remains unknown (Chapter 8.2). Neither is it clear whether existing international conventions and policy instruments are sufficient to tackle the potential harmful effects of fertilizer. Conventions mostly address a specific issue, while fertilizer use is associated with many issues.

The existence of international partnerships and initiatives addressing fertilizer distribution and use (Chapter 8.3) has helped to ensure the provision of scientific input to international decisions, as demonstrated through the progress made by the International Technical Panel on Soils of the Global Soil Partnership (GSP), hosted by the FAO, in developing outputs such as the International Code of Conduct for the Sustainable Use and Management of Fertilizers (FAO 2019). The Code provides a locally adaptable framework and voluntary set of practices and is targeted at diverse stakeholders. Another example is provided by recent developments regarding nitrogen, in which the International Nitrogen Management System (INMS) project, implemented by the UNEP and executed by the International Nitrogen Institute (INI) and its partners, has continued to play a leading role (INMS 2021).

Bottlenecks exist in the case of many conventions, as well as international partnerships and initiatives, as their success depends on the willingness and capacity of the Parties or members to comply with them. On the other hand, their existence provides an opportunity or platform for global and regional discussions on sustainable fertilizer use.

Regional agreements

In general, regional agreements tend to focus more on trade than on environmental issues (Chapter 8.4). However, trade agreements increasingly include environmental provisions (George 2014) and could therefore contribute towards sustainable nutrient management.

There has been a push to achieve regional harmonization of direct fertilizer policies (e.g., harmonization of quality pricing and sustainable use), but progress has been variable. Harmonization of regional fertilizer policies can benefit both producers and consumers by

opening up markets, reducing trading costs, and encouraging sustainable use of quality fertilizers. The harmonization and implementation of such policies is more advanced in developed countries with shared markets (e.g., in the European Union [EU]) than in developing countries (e.g., in sub-Saharan Africa) (Chapter 8.4).

The existence of regional platforms in many regions offers an opportunity to develop and implement regional agreements on fertilizers. Nevertheless, attempts to harmonize environmental policies, as well as the success of such measures, are hampered by national interests, lack of funds and lack of capacity.

National legislation and regulations

National legislation

Legislation in many countries targets fertilizer use. However, in many other countries legislation dedicated to fertilizers may be lacking; legislation may be present although gaps exist; or legislation may be fragmented (Chapter 8.5).

Bottlenecks in the development of national policies include lack of adequate scientific evidence for policy development, lack of adequate funding, and inadequate staff capacity. Furthermore, some existing legislation may not support sustainable fertilizer use or may even conflict with fertilizer policies that it would be desirable to implement. For example, in developed countries there has been an emphasis on specialization instead of diversification, so that livestock regions are sometimes far from crop producing regions. This can make it difficult to use manure in crop production (e.g., due to high transportation costs). Where land is limited, disposal of such manure also becomes a problem.

Fertilizer evaluation, registration, licensing and labelling

The evaluation and registration of fertilizer products, and the registration of dealers, can help ensure the safety and quality of fertilizers on the market. Labelling can also provide assurance to buyers of the quality and quantity of fertilizer products.

In general, sub-Saharan African (SSA) countries are the worst performing in this respect (Chapter 8.5). In many of these countries there are only rudimentary regulatory frameworks for fertilizer registration; registration time is very long and costs are high; and quality control is poor. In some countries fertilizers are considered new products even when they are made by mixing registered fertilizers. Moreover, in many countries the long and expensive process of registration and licensing discourages small firms from entering the fertilizer industry. Many SSA countries lack personnel and laboratory facilities adequate to implement regulations efficiently. Countries in other regions (Asia and Latin America) also perform poorly or fairly poorly with regard to fertilizer registration, according to the World Bank's Enabling the Business of Agriculture (EBA) study, which collects data on regulations that affect farmers (World Bank 2021a). No reviews or reports were found on the reasons behind this poor performance.

Countries that have not yet been successful in implementing regulatory and policy measures can learn from those that have been more successful. Increasing public participation (e.g., through food labelling) can provide a way to improve the effectiveness and efficiency of these measures. Food labels in most countries include information on nutritional value and expiry dates, but rarely on products' environmental footprint. The European Commission intends to propose that food labels include information concerning climate, environmental and social impacts (European Commission [EC] 2020). Support for such moves could come from bodies or platforms that encourage documentation of the environmental footprint of food production, such as the European Food Sustainable Consumption and Production Round Table (EC 2019) (Chapter 8.4). Key bottlenecks include lack of funding and the unwillingness of governments to put supporting policies in place; lack of quality data; administrative costs; and the variability of the supply chain.

Control, enforcement and monitoring measures

While control, enforcement and monitoring of fertilizer quality is required in many countries, implementation of these measures is often poor

(Table 11.2-1). In the case of manure, enforcement varies across countries and some countries have contradictory policies (Chapter 8.5.2). Monitoring programmes for pollutants are lacking in some countries.

Implementation of these measures is mainly constrained by lack of capacity (e.g., trained staff, laboratories and other facilities, finance) and the complexity of environmental damage caused by fertilizers. In some countries several institutions with overlapping mandates are involved in implementation, which reduces efficiency and effectiveness. Furthermore, it is easier to implement measures that target the industry (e.g., fertilizer distributors and sellers) than those targeting farmers.

As with other measures, experience gained elsewhere can be applied to improve the success of regulations. Greater awareness of fertilizers' health impacts on the part of policymakers, together with public pressure, can influence government decisions. There is also a need to establish food, feed and water monitoring programmes for pollutants that could potentially

Table 11.2-1 Regulatory and policy measures used to reduce the environmental and health risks of fertilizers: strengths, limitations, opportunities and challenges.

Measure	Strengths	Limitations	Opportunities	Challenges
International conventions (Chapter 8.1)	Address transboundary risks, set international standards for nutrient pollution risk reduction	None specific to fertilizers	Existence of international frameworks provides an opportunity for international discussions	Effectiveness mostly depends on national governments' willingness and capacity to comply
Regional agreements (Chapter 8.3)	Address transboundary risks and set regional standards	More focused on trade and less on environmental issues	Existing regional frameworks and trade agreements offer opportunities to implement fertilizer agreements	Effectiveness depends on national governments' willingness and capacity to comply
National fertilizer legislation, and legislation that indirectly addresses fertilizer use (Chapter 8.4)	Provide a legal basis to require risk reduction measures	Lack of legislation that comprehensively addresses risks arising from the use of fertilizers	Synergies among different pieces of legislation can be exploited	Lack of scientific evidence for policy development Unwillingness of governments to develop legislation Policies could be fragmented
Fertilizer evaluation, registration, licensing and labelling (Chapter 8.4)	Most countries require fertilizers to be evaluated before registration and to have labels, which contribute to increased awareness	Personnel and laboratories limited Registration time consuming and expensive Duplication of efforts by regulatory authorities	Existence of efficient and effective measures provides a learning opportunity Increased awareness of environmental issues among stakeholders	Governments may be unwilling to provide adequate resources, or to put supporting policies in place
Control, enforcement and monitoring (Chapter 8.4)	Mostly required for fertilizer before it gets to the farmer Required in many developed countries, but rarely in developing ones	Control, enforcement and monitoring are often inadequate The three measures are sometimes carried out by different authorities	Some experience exists in monitoring ecosystem damage Increased awareness of environmental issues among stakeholders	Governments may be unwilling to provide adequate resources or to reorganize the fertilizer regulatory process

be from fertilizers, and to establish risk assessment goals and methods. Information collected through such programmes can be used to inform decision-makers.

Major drawbacks to the success of control, enforcement and monitoring measures include unwillingness by governments to provide support, and to reorganize and reduce the number of authorities involved.

11.2.2 Market-based measures

Key market-based measures include taxes, subsidies, grants, and commodity price support for harvested produce. This report mainly focuses on subsidies and taxes.

Subsidies

Many developing countries provide fertilizer subsidies to increase food production, improve farmers' incomes and support the growth of the fertilizer industry. However, subsidies have been associated with an unbalanced supply of nutrients to the soil, inefficient fertilizer use, substantial pressure on national budgets, and market distortions (Chapter 7.5.1; Chapter 8.5.4; Table 11.1-2).

Some countries have had more success with subsidies than others, although this could present a learning opportunity for the latter. For example, subsidies became more successful in sub-Saharan Africa when modifications were made to their design. In addition, technologies can be subsidized that improve the efficiency of fertilizers and their use (e.g., precision farming) and encourage recycling of nutrients to address both food demand and environmental issues (Table 11.2-2). For example, in China, government is trying to reduce growth in demand for inorganic fertilizers by phasing out subsidies for inorganic fertilizers and subsidizing the manufacture and use of organic fertilizers (Box 11.2-1). Successful use of subsidies can be hampered not only by the pressure they exert on national budgets, but also by smuggling of subsidized fertilizers to neighbouring countries.

Taxes

Taxes on fertilizers may contribute to sustainable nutrient management and reduced pollution.

Table 11.2-2 Market-based measures used to reduce the environmental and health risks of fertilizers: strengths, limitations opportunities and challenges.

Measure	Strengths	Limitations	Opportunities	Challenges
Subsidies (Chapter 8.4)	Keep fertilizer prices low, increase fertilizer use Improve food security in developing countries Subsidies for proven technologies can reduce nutrient losses	Not always efficient Can distort the market Can encourage imbalanced nutrition	Experience from successful countries can benefit other countries More successful when combined with other policy measures	Funds may be lacking Subsidized fertilizer and produce sometimes sold in neighbouring countries Some subsidy programmes lack an exit strategy International and regional trade agreements discourage use of subsidies Can encourage smuggling of fertilizers
Taxes (Chapter 8.4)	Fertilizer taxes can reduce fertilizer use and pollution. Tax credits (e.g. for organic inputs) can encourage their use	Have had limited success Mostly designed to raise revenues and not to reduce pollution	The funds raised can be used to pay for implementation, e.g. of regulatory measures	Can reduce competitiveness of produce on the regional or international market Can encourage smuggling of fertilizers

Box 11.2-1 Fertilizer-related measures in China.

China is the world's leading consumer of inorganic fertilizer. At the same time, pollution from agriculture in that country is of increasing concern. Nutrient loss from crop and livestock systems has been associated with air pollution and contamination of surface water and groundwater (Ma, Hou and Bai 2020). Agriculture has also been linked to greenhouse gas (GHG) emissions. For example, according to an analysis by Mamun, Martin and Tokgoz (2019) inorganic fertilizer emissions in 2015 accounted for 29.2 per cent of all agriculture-related GHG emissions in China compared to the global average of 13.4 per cent.

In general, crop and livestock systems are decoupled in China, which has led to less recycling of nutrients in animal manure back to land (Ma, Hou and Bai 2020). Furthermore, where farmers grow crops and own livestock, manure production sometimes exceeds nutrient requirements for crop growth (Jin *et al*. 2021). In addition, nutrient use efficiencies have declined (Ma, Hou and Bai 2020).

In the past, government fertilizer policies encouraged fertilizer production, distribution and use, and livestock policies encouraged livestock production (Ma, Hou, and Bai 2020). According to a World Bank report by Searchinger *et al*. (2020), until 2015 China provided subsidies for the production of fertilizers and also imposed limitations on imports. For example, under the Agricultural Input Comprehensive Subsidies programme it spent a total of United States dollars (USD) 16.6 billion in 2014 (OECD 2018, cited in Mamun, Martin and Tokgoz 2019). Fertilizer subsidies likely contributed to excessive use of nitrogen fertilizers, contributing to nutrient pollution in surface and groundwater in agricultural areas (Searchinger *et al*. 2020).

In 2015 the Action Plan for the Zero Increase of Fertilizer Use was implemented (Ji, Liu and Shi 2020). Its key objective was to achieve zero growth of inorganic fertilizer use on major crops by 2020. After the plan was implemented, use of inorganic fertilizers declined while the amount of food produced did not decrease (Ji, Liu and Shi 2020). The lack of yield reduction can be attributed partly to the excessive amounts of fertilizers previously used, as well as to increased promotion of soil testing and use of formulated fertilizers (i.e. fertilizers with a chemical balance formulated to meet local needs) (Shuqin and Fang 2018; Ji, Liu and Shi 2020).

China has currently phased out fertilizer subsidies (Searchinger *et al*. 2020) and, as of 2019, applied a zero export tariff on all fertilizers and potash products (Argus 2018). It has also increased efforts to support pilot programmes targeting nitrogen use efficiency (Searchinger *et al*. 2020). Existing nitrogen use efficiency programmes have been expanded (e.g. for maize) and new ones initiated (e.g. for vegetables) (Searchinger *et al*. 2020).

The government has set a 75 per cent target for manure use by 2020 (Ministry of Agriculture 2017, as cited by Ma, Hou, and Bai 2020). There are also increased efforts to use livestock manure in crop production. For example, in a programme initiated on the substitution of inorganic fertilizers by organic ones, subsidies are provided to organic fertilizer manufacturers to increase affordability and uptake (Searchinger *et al*. 2020).

Additional measures include providing tax holidays for the producers of organic fertilizers; supporting entities for the collection, storage and transportation of raw materials of organic fertilizer; implementing a subsidy policy on organic fertilizer usage; and providing subsidies for equipment used in the production and use of spread organic fertilizer (SOHU 2018). According to a review by Zhang *et al*. (2020), in China partial substitution of inorganic fertilizers by manure can increase crop yields and, depending on conditions, can decrease ammonia and nitrous oxide emissions.

The government has also scaled up programmes to improve water use efficiency and soil quality (Cassou 2018). Suggestions have been made for additional actions, such as improving linkages between livestock and croplands at a regional scale (Jin *et al*. 2020) and between farmers and R&D (Searchinger *et al*. 2020).

They can also result in reduced crop production (Chapter 8.5.4; Table 11.2-2). However, few countries have environmentally related fertilizer taxes and, where these taxes have been used, they have not been very successful.

Lack of success with taxes on fertilizers is partly due to their often being designed primarily to raise revenue rather than to curb nutrient pollution. They also tend to have low elasticities (i.e., price changes have little or no effect on demand), are sometimes set too high, are costly to enforce, and may disadvantage a country on the international market. Ploughing agricultural tax revenues back into the agricultural sector can increase the political acceptability of this tax (Sud 2020).

11.2.3 Training and awareness building

Awareness of the of the adverse impacts of fertilizers and ways to minimize these impacts differs among knowledge disseminators, farmers and other stakeholders. Measures that encourage adoption of best practices include effective education and training programmes for knowledge disseminators and farmers; effective extension systems; and ensuring that adoption of best practices will improve farmers' economic welfare (Chapter 7.5.1). No literature was found on improper use of fertilizer and gender at the time the report was being drafted, however the research focus on this topic was not exhaustive.

Education and training programmes

A key objective of agriculture-related education programmes is to equip knowledge disseminators with appropriate knowledge and tools. These programmes sometimes have limitations. Not all of them have an up to date curriculum addressing environmental issues. This may be especially true in developing countries, where the focus has largely been on food security and poverty reduction whereas in developed countries the focus has included surplus production and environmental degradation (Suvedi and Kaplowitz 2016). However, there have been efforts in many universities globally to ensure that the Sustainable Development Goals (SDGs) and sustainability are included in teaching programmes (Filho *et al*. 2019).

There is need in many countries to promote ecological agriculture curricula and courses and to support updating of the curricula of fertilizer-related training programmes to include the potential risks of fertilizers and the benefits of sustainable nutrient management. There is also a need for regular updating of the curricula for both formal and informal training to correspond to changing priorities and emerging research evidence. In addition, in developing countries there has been a decline in the number of students taking agricultural courses since they prefer careers that are more financially rewarding and see little prospect of earning a good living in agricultural professions.

The existence of national agricultural education and national accreditation boards provides an opportunity for external oversight of the education curriculum. Including environmental experts in such bodies helps to ensure that environmental issues are not neglected and that curricula are kept up to date. Increased use of information and communications technology (ICT) in agriculture has contributed to an increase in the number of young farmers and may also contribute to an increase in the number of agricultural students. Nevertheless, the issue of funding will need to be addressed.

Extension services and knowledge dissemination

Extension services convey knowledge to farmers and train them on new practices. Extension staff In many countries are well trained. However, there has been a decline over the years in the number of public extension staff, along with high staff turn-over in some countries, as reported in Zambia by Somanje, Crespo and Zinyengere (2017) and in Ethiopia by Bitzer (2016). This has made extension coverage worse, especially in developing countries due to the large number of smallholder farmers in those countries. In addition, in some countries funding has declined and links between extension, research and farmers are sometimes weak. Furthermore, where there is more than one service provider, extension messages from different providers are sometimes not harmonized.

Apart from government sponsored extension services, non-traditional knowledge disseminators (e.g., the fertilizer industry, non-governmental organizations [NGOs], research organizations, service providers, and farmer groups and cooperatives) have proved effective in many parts of the world (Mittal, Padmaja and Ajay 2018; Ingram and Mills 2019). A recent study on changes in agricultural extension by Norton and Alwang (2020) reported that knowledge transfer has increasingly shifted from the public sector to include private advisory services, although more so in developed than in developing countries. It associates that shift with agricultural commercialization.

Currently in developing countries there are efforts to empower (jobless) youth to become knowledge disseminators, for example in sheep farming in Ethiopia (Wamatu and Ephrem 2020). Involving youth brings in knowledge of ICT and can help make it possible for a greater number of people to use cheap communication technologies.

Knowledge dissemination can be improved through strengthening the training of agronomists, extension agents, input distributors and other knowledge disseminators on new technologies. Since adulteration of fertilizer is an issue in some countries (Chapter 7.4.6), training farmers how to identify counterfeit and adulterated fertilizers (where such information exists) can contribute to efficient fertilizer use.

Adoption of practices and technologies by farmers

According to a survey of experts carried out for this report, in developing countries many fertilizer recommendations are not based on scientific research. Moreover, the information gap with regard to the adverse environmental and human health effects of fertilizers (Chapters 9 and 10) is a strong indication that recommendations do not usually take these adverse effects into consideration. Knowledge about fertilizer use and its potential impact also varies among farmers. For example, many farmers need to be trained on (or made aware of) fertilizer options that have proven successful (e.g., use of neem-coated fertilizers, precision farming, precision conservation, nutrient recycling, mixed cropping, the 4R approach and manure management) (Chapters 7.2.6 and 7.5.1). Adoption of such options can be enhanced through participatory and experience-based learning, with specific attention given to building the capacity of youth and women. Farmers may be unwilling to adopt such measures due to cost implications. Subsidizing sustainable practices is likely to encourage farmers' adoption of environmental measures.

Public awareness and action

Most fertilizer-related conversations are between policymakers, researchers, knowledge disseminators, fertilizer users and the industry (Chapters 7 and 8). Since fertilizer use can have negative social impacts (Chapter 10), including relevant NGOs in decision-making can improve the chances of success of fertilizer policies. For example, involving the public in nutrient recycling research could reduce consumer aversion to food grown with sewage. Furthermore, participation of environmental civil societies, for example environmental non-governmental organisations (ENGOs) in such conversations has been associated with reduced emissions, for example carbon emissions (Grand and Vasi 2017).

An informed public can push for development and implementation of environmental policies (Table 11.2-3). However, lack of adequate knowledge by the public sometimes discourages the adoption, for example, it may reject food grown with recycled nutrients (Box 11.2-2).

Impediments to the public's contribution to reduced nutrient pollution include the fact that the issue may not be a priority for the public, that public activities may not be well coordinated, and that such activities are rarely funded. Furthermore, the public may be unwilling to act, especially where proposed changes affect their lives. For example changing dietary habits has been proposed as one way to reduce fertilizer use (Chapter 7.5.2), but some people are unwilling to make such changes despite their awareness of adverse impacts (Macdiarmid, Douglas and Campbell 2016).

To improve the chances of success of stakeholder participation, lessons learned from successful public actions can be applied and existing civil society organizations can serve as platforms to push for government action. Challenges to public actions include lack of support for such actions in national laws, and the fact that donors may be unwilling to fund such actions.

11.2.4 Research and development

Research and development (R&D) can influence risks through generating new knowledge. Evidence-based policies and interventions/ recommendations are key to maximizing the benefits of fertilizers and reducing their risks.

Table 11.2-3 Educational measures used to reduce the environmental and health risks of fertilizers: strengths, limitations, opportunities and challenges.

Measure	Strengths	Limitations	Opportunities	Challenges
Education, training programmes	Train knowledge disseminators on best practices for healthy environment	Education curricula are sometimes outdated Declining numbers of agricultural students, especially in developing countries	Existence of committees of environmental experts and national accreditation boards, provides an opportunity for curriculum oversight Use of ICT in agriculture encourages (and is encouraged by) youth interest	Reduction of training budget by governments
Extension services	Convey messages on sustainable fertilizer use and management to farmers Extensive coverage Qualified staff	Decline in numbers of extension staff Inadequate training Inadequate funding Weak links with research and farmers Lack of harmonized messages among extension actors	Increased use of ICT Increased collaboration, e.g. public-private partnerships Multiple extension service providers present Jobless youth in some countries are trained as extension agents	Government and donors may be unwilling to invest more in extension services
Application of environmental measures by farmers	Adoption can contribute to healthy environment	Many recommendations are not based on scientific research Farmers lack adequate knowledge about fertilizer use and risks Farmers are primarily interested in economic benefits and not environmental issues Resistance to change Farmers are too numerous to be effectively trained and monitored	Increasing environmental awareness among both farmers and consumers Existence of trade agreements and voluntary standards that aim to reduce environmental damage	Global competition among producers Lack of an enabling environment
Public awareness and action	The public can push for development and implementation of environmental policies Society is interested in environmental issues	Public awareness does not necessarily translate to cleaner environment Lack of coordinated action by public Unwillingness to change	Experience of successful public actions can be applied Existence of civil society organizations for environmental issues	National laws may not support public action Funding may be lacking

Generation of new knowledge and technologies

As demonstrated in earlier chapters, there are large information gaps in the body of knowledge about fertilizer use and management. For example, many studies have been carried out on the agronomic and economic benefits of fertilizer use, a fair number on the environmental effects of nutrient pollution, and a few on health benefits, but studies exploring all these areas together are lacking (Chapter 10). Furthermore, there is a need to develop and improve recommendations. Where it is necessary to address all parameters in the same recommendation, this can be challenging.

Box 11.2-2 Use of sewage sludge in Sweden. Kirchmann *et al.* (2017).

In Sweden measures to control metal emissions in sewage sludge have been very successful. For example, concentrations of heavy metals in municipal sewage sludge decreased by up to 90 per cent between the 1970s and 2010. This has resulted in reduced heavy metal concentrations in the soil in general, and in increased soil microbial biomass.

However, only about 20 per cent of the total amount of organic water produced is recycled. Reasons for this lack of use range from resistance among industries and consumers to products grown on land treated with sewage sludge, to that associated with bulkiness and concerns about the profitability of applying the sludge to land. Extracting nutrients from waste to produce concentrated fertilizers, instead of recycling wastes directly to soil, could encourage nutrient recycling. However, it calls for new extraction technologies.

Research activities have continued to be affected by shifts in research priorities, the decline in the number of researchers, and a decline in funding in some regions (Table 11.2-4). In the United States funding of agricultural research by the public sector fell from the early 2000s, while private sector funding increased (United States Department of Agriculure [USDA] 2019). The role of the private sector in agricultural research, including through funding, has continued to expand (Fuglie 2016). In developing countries research is underfunded, although in some countries (e.g., China, a key middle income country) funding has continued to increase (Beintema and Echeverría 2020). Research efforts have sometimes been unbalanced; for example, studies on plant biomass have tended to focus on above ground biomass and ignore root biomass (Chapter 7.5.2). Furthermore, research efforts in the past were uncoordinated, but today there is increased collaboration among donors, scientists and other stakeholders.

To contribute to closing data and technology gaps, there is a need to support the formation of open data inventories (e.g., for scientific publications) at international, regional and national levels to make data freely accessible to scientists and other users. Sharing data among scientists, for example through Open Science, can speed up the development of research outputs and minimize costs, although some scientists are unwilling to share their data (Wolkovich, Regetz and O'Connor 2012; Haddaway 2018). Some countries, such as the United States (Box 11.2-3), as well as organizations and institutions (Box 11.2-4), are making efforts to improve public access to publications and data generated by scientists. To fill knowledge gaps,

Table 11.2-4 Research and development measures used to reduce the environmental and health risks of fertilizers: strengths, limitations, opportunities and challenges.

Measure	Strengths	Limitations	Opportunities	Challenges
Generation of new knowledge	Generates knowledge on sustainable fertilizer use and management Interdisciplinary approach	Decline in number of national research staff, lack of adequate funding Research is sometimes uncoordinated and unbalanced	Existing collaborations can be involved in research Donors are increasingly pushing for data sharing to speed up production of quality scientific outputs Demand for research outputs Existence of supportive polices	Research is costly and funds are sometimes lacking Donor fatigue Research priorities may differ between a country and donor

Measure	Strengths	Limitations	Opportunities	Challenges
Transfer of research findings to knowledge disseminators	Allows application of research findings	Funds for knowledge transfer not always included in project budget Researchers more interested in data publishing than dissemination Language used by scientists not easily understood by non-scientists	Existing collaborations. e.g. the Global Partnership on Nutrient Management (GPNM), regional soil partnerships and INI, can be used to disseminate knowledge Increased use of ICT	Donors are sometimes unwilling to fund End user priorities can change Lack of consensus among scientists sometimes leads to conflicting messages

Box 11.2-3 Ensuring access to federally funded research in the United States.

It is estimated that between 2015 and 2017 the United States Government spent an average of USD 135 billion per year on scientific research and development across various disciplines, including medical sciences, public health and agriculture (United States Government Accountability Office [GAO] 2019). Efforts within the government to ensure that scientific papers and publications resulting from federally funded research are freely and easily accessible have grown in recent decades. For example, the Congress passed legislation in 2008 (United States Congress 2008) mandating that research papers funded by the National Institutes of Health (NIH) be made publicly available, at no charge, no later than one year after publication through the National Library of Medicine's PubMed portal (United States National Library of Medicine 2021).

With the goal of expanding these earlier legislative efforts, in 2013 the Office of Science and Technology Policy (OSTP) issued a memorandum that directed federal agencies with over USD 100 million in annual research expenditures to develop a plan to ensure public access to products from federally funded research within 12 months of publication of a given article (United States Office of Science and Technology Policy [OSTP] 2013). By 2017, the 19 federal agencies that met the annual expenditure requirement in the 2013 memorandum had developed the requested access plans (The White House, United States 2016). For example, as part of the Department of Agriculture's plan to increase access to federally funded research the National Agricultural Library developed PubAg, an online search portal that provides access to over 300,000 scientific journal articles focusing on agricultural research (USDA 2021). Similarly, the United States Geological Survey (USGS) launched the USGS Publications Warehouse, which currently provides access to over 160,000 publications written by USGS scientists (United States Geological Survey 2021). Along with these efforts by federal agencies, there have been bipartisan attempts by members of Congress to enact companion legislation, such as the Fair Access to Science and Technology Research Act (FASTR) (United States Senate 2017), with the same goals as the 2013 OSTP memorandum but better accounting for publications produced by extramural researchers working outside the federal government.

A 2019 analysis of the public access plans by the GAO found that there had been overall progress across the government in increasing public access to federally funded research, but that some additional steps could be taken by agencies (GAO 2019). The GAO made 37 recommendations to the 19 agencies about ways they could comply more fully with their obligations under the 2013 OSTP memorandum. For example, it recommended that USDA complete development of training for employees involved in reviewing the merits of researchers' proposed data management plans. Agencies by and large concurred with the GAO's recommendations and committed to working during the next few years to address the specific recommendations. OSTP is currently reviewing public comments on a Request for Information (RFI) issued in February 2020 (OSTP 2020) on several topics related to furthering public access to federally funded scientific research.

These efforts to ensure easy and free access to federally funded research mirror efforts in Europe to require that State-funded research products are published in an Open Access format. The Plan S initiative, launched in 2018 by cOAlition S, is a consortium of national research agencies and funders from 12 European countries (Plan S 2021).

Box 11.2-4 Examples of international initiatives to make data and publications accessible.

Scientists around the world publish thousands of articles every year in journals that cover research from various disciplines. Access to most of these scientific journals by scientists looking to publish their research, or anyone who wants to read the articles, may require the payment of fees that can sometimes be very costly. While there have been recent efforts by many publishers to make articles Open Access (which means anyone can download material), this service relies on authors of the paper paying even higher submission and publishing fees. Therefore, obtaining access to high-quality, cutting-edge scientific research is a problem not only for members of the scientific community, but also for policymakers who need to be able to read reliable, evidence-based, peer-reviewed scientific papers to inform their law-making efforts.

Open access databases include organization databases with data accessible to all, such as those of the FAO (FAOSTAT 2021) and the World Bank (World Bank 2021b), and initiatives such as Global Open Data for Agriculture and Nutrition (GODAN), which focuses on building high-level policy, and public and private institutional support for open data (Global Open Data for Agriculture and Nutrition [GODAN] 2021).

Initiatives exist that aim to make scientific publications more accessible – in terms of cost and technology – to institutions and individuals, with some efforts placing emphasis on ensuring access to those in low income countries. For example, Google Scholar is not only a search engine for scientific literature from journals and libraries around the world, but also provides users with copies of papers if they are available. Research4Life Programmes provides low and middle income countries with access to scientific and professional resources through the following programmes:

- AGORA (Access to Global Online Research in Agriculture), a partnership between FAO and Cornell University in the United States, along with international publishers (AIMS 2020);
- ARDI (Access to Research for Development and Innovation), coordinated by the World Intellectual Property Organization (WIPO) and international publishers (World Intellectual Property Organization 2020);
- GOALI (Research for Global Justice), managed by the International Labour Organization (ILO) in collaboration with the Cornell Law School Library and the Lillian Goldman Law Library at Yale Law School, both in the United States (International Labour Organization 2021).
- Hinari Research for Health, managed by the World Health Organization (WHO) in partnership with the Yale University Library in the United States and international publishers (World Health Organization 2021);
- OARE (Online Access to Research in the Environment), managed by the United Nations Environment Programme (UNEP) in partnership with the Yale University Library and international publishers (UNEP 2021);

In addition, academic social networks like ResearchGate allow researchers to share their publications with others interested in their research (ResearchGate 2021). There are concerns about the potential for such sites to violate intellectual property laws in various countries. Nevertheless, these sources generally not only provide users with access to some publications posted by the authors, but also make it possible to communicate with them directly.

providing access to information can be coupled with regular systematic reviews and synthesis of existing knowledge.

In addition to data gaps on the impacts of fertilizer use, research efforts can include approaches to the development of fertilizer recommendations that are simple to use and do not require too much data; breeding and screening for improved nutrient use efficiency; and improved nutrient recycling technologies.

Transferring knowledge from research

Ideally, research findings should be communicated to end users, but this does not always occur in practice.

Shifting from the traditional linear research approach (in which scientists generate new knowledge and then hand it over to end users or for knowledge dissemination) to working with stakeholders on knowledge generation has had some success. This change in approach has partly been due to pressure from donors who insist that research projects have an impact. However, it, too, is challenged by lack of funding.

The success of R&D can be improved by enhancing collaboration between stakeholders (e.g., strengthening public agricultural R&D systems; supporting collaboration between R&D systems, the public and private sector, and farmers; supporting the development and dissemination of targeted innovations for the use of different types of farmers; and promoting farmer characterization and using such information in technology dissemination). International partnerships and initiatives providing support to knowledge transfer efforts include the Global Partnership on Nutrient Management (GPNM) (UNEP n.d.) and the Sustainable Agriculture Initiative (SAI) Platform (Sustainable Agriculture Initiative [SAI] Platform 2021) (Chapter 8.3).

The use of scientific knowledge can also be improved by strengthening science-policy interfaces at international, regional and national levels; having communication strategies in place at all levels; and designing and developing responsive, audience-oriented knowledge products that target different audiences (e.g., policymakers, extension agents, farmers) and incorporate feedback loops.

11.3 Strengthening fertilizer management: options for actions

In this section incremental actions are proposed that can strengthen existing risk reduction and risk management measures for fertilizers.

In Chapter 12, transformative actions are proposed. These actions would more fundamentally change the way nutrients and fertilizers are managed.

As discussed in the previous sections of this chapter and in Chapters 7, 8, 9, and 10, in many countries there are already measures promoting sustainable use and management of fertilizers. However, the degree of implementation and the success of these measures vary. In addition, there are countries that do not have the relevant policies or in which there are policy gaps. This section sets out some of the actions that have already been undertaken, but may require incremental adjustments to achieve sustainable fertilizer use and management.

11.3.1 Strengthening governance of the production, trade and use of fertilizers

Update national fertilizer legislation to include all elements of the fertilizer life cycle

In many countries there is need to expand fertilizer policies to include not just inorganic fertilizers, but also organic fertilizers, as well as all elements of the fertilizer life cycle. Fertilizers are subject to various types of legislation and regulations related to production, trade, distribution, marketing, safety and use, which can vary among, or within, countries (FAO 2019a) (see Box 8.5-1). Reviewing and updating policies to address gaps is essential for sustainable nutrient management. There is a need, subsequently, to develop, review and update legislation in line with the expanded fertilizer policies.

Fertilizers can be directly regulated by specific fertilizer legislation (addressing, for example, the registration/authorization of fertilizers on the market and their quality, labelling and packaging) or can be addressed in general agrochemicals or agricultural inputs legislation. There are also other laws that may influence the regulatory framework for fertilizers and introduce specific rules or restrictions (see Box 8.5-1).

Enhance enforcement capacity to bolster effective implementation of national legislation

Where monitoring is hampered by lack of trained personnel and equipped laboratories, enhancing enforcement capacity can bolster effective implementation of national policies and related legislation. Strengthening implementation of fertilizer quality inspection and control systems, for example by setting up of a spot check system, training staff and updating analytical equipment, is also necessary.

Establish or strengthen regional collaboration on fertilizer management and, where relevant, regionally harmonize fertilizer legislation

Regional collaboration on fertilizer management does not exist in some regions or, if it does, collaboration may not be effective. This is true even in regions with cross-border trade of fertilizers and shared water bodies. Yet such collaboration would make it easier to control the quality of fertilizer used in regions and make fertilizer registered in one country readily acceptable in other countries. Hence, establishing or strengthening regional collaborations is beneficial for all countries in terms of the environment and human health, economic costs and time (see chapter 8).

Strengthen national collaboration on policies and programmes

National policies and programmes for sustainable use and management of fertilizer are sometimes in conflict with, for example, policies and programmes targeting food security and economic welfare. Harmonizing such policies and programmes (e.g., between the agricultural sector and related sectors such as water, energy and health) can reduce or eliminate incoherence and create synergies. Furthermore, establishing and supporting interdisciplinary platforms for stakeholder engagement can strengthen coordination, implementation and monitoring of fertilizer policies

Promote mainstreaming of fertilizer policies in relevant international and regional agreements

Although many international/regional agreements and agendas (e.g., on food quality) include sustainable development among their guiding principles, minimizing nutrient pollution is not an objective of some of them. Mainstreaming fertilizer policies in such agreements and agendas can contribute to increased stakeholder actions on sustainable nutrient management.

Ensuring the availability of suitable and affordable fertilizers

The amount of fertilizer used per unit of land in some low and middle income countries is low. It is particularly minimal (averaging below 50 kg/hectare/year) in sub-Saharan Africa, where yields are low and many people do not have access to sufficient and nutritious food. A major reason for lack of access to affordable fertilizer is that fertilizer prices there are higher than in other regions. Provision of affordable fertilizer in all world regions should be accompanied by controls (e.g., on quality and the use of suitable practices and technologies to minimize adverse impacts).

11.3.2 Strengthening monitoring of fertilizers use and effects

Collect statistics on manufacturing, importation, sales, use and storage of fertilizers

Not all countries have reliable and readily available national data on fertilizer manufacturing, importation, trade, use and bulk storage (in particular, for hazardous fertilizers such as ammonium nitrate). Yet data on manufacturing, importation, sales and use are crucial for national planning and budgeting, while hazardous fertilizers need to be stored safely. Ensuring the collection and sharing of such data should contribute to improved decision-making.

Establish monitoring programmes on pollutants that could potentially be from fertilizers

Countries in which there are no national monitoring programmes for key pollutants that could potentially be from fertilizers should consider

setting up such programmes, as monitoring data help to identify problems and determine whether control measures are working. Setting up national monitoring programmes for such pollutants in food, feed and drinking water, as well as in coastal waters and in other environmental matrices is becoming increasingly urgent due to intensification. These programmes should consider all key potential sources of such pollutants.

Ensure feedback into policy and decision-making

There is need to set up national reporting systems to ensure that information generated on the fertilizer life cycle informs decision-making concerning the authorization and use of fertilizers. This information could also be shared and used at both regional and international levels.

11.3.3 Innovating fertilizer management through targeted R&D

Promote multi-stakeholder innovation

Collaborative partnerships are essential for efficient and effective research. Developing fertilizer recommendation tools and fertilizer question and answer (Q&A) platforms, in collaboration with fertilizer manufacturers, other service providers and end users, can enhance the adoption of innovations and knowledge.

Strengthening public agricultural research and development systems through capacity building and funding, and supporting related collaborative public-private R&D partnerships, should be considered in countries where the number of public researchers is limited and public research activities are underfunded.

Assess costs and benefits

The large data gaps described in this report demonstrate that there is a need for increased research efforts, especially on the impacts of fertilizer use but also on sustainable management options for various agroecological conditions. Including key economic variables associated with the use of fertilizers in such assessments would provide comprehensive evidence concerning the environmental and human health effects of fertilizers; provide information about the actual status of the problem of nutrient pollution; and contribute to innovations in nutrient management.

Regularly review existing knowledge

To increase accessibility of information, countries should consider providing support to the formation of open data inventories (e.g., for scientific publications and research data) at national, regional and international levels; ensure the compilation of fertilizer statistics; and establish innovative approaches for regular systematic reviews of existing knowledge. This would improve the usefulness of research information in decision-making.

11.3.4 Informing and educating for change

Ensure provision of information to farmers and other stakeholders

Scientifically sound decision-making should be promoted at agroecosystem and regional level. Related information should be made available to all stakeholders in appropriate forms.

Countries should ensure that farmers have access to and exchange information about new technologies for fertilizer use and nutrient management. Where necessary (in sub-Saharan Africa, for example, where literacy rates are low), countries should promote participatory and experience-based learning to ensure long-term adoption of sustainable practices and technologies, with specific attention given to building the capacity of youth and women.

Use of ICT and social media is increasing even in low and middle income countries, although the increase is less for women and the rural population. Making better use of these technologies to provide information and complement education and training, while ensuring that marginalized groups are included, is a cost-effective way to support communication.

Include sustainable nutrient management in educational curricula

Countries should promote ecological agriculture courses in schools, universities and other relevant training entities in order to close the gap between the training offered and the development agenda. Supporting the updating of the curricula of fertilizer-related training programmes to include the potential risks of fertilizers and the benefits of sustainable nutrient management, integrated nutrient management, and environmentally friendly nutrient management technologies and practices can ensure that students are better equipped to guide farmers in sustainable nutrient management.

Train farmers on how to identify adulterated fertilizers

Countries where counterfeit and adulterated fertilizers are common should consider training farmers to identify such fertilizers, where such information exists. That knowledge will allow farmers to have more confidence in the quality of the fertilizer they purchase and discourage overapplication. Training should be accompanied by putting in place a system for reporting such malpractice.

Strengthen extension services

Dissemination of information to farmers, especially in middle and low income countries, is hampered by lack of adequate extension capacity. Countries should consider strengthening public agricultural extension systems, and other independent advisory services, and coordinating advisory services.

Support development of national, regional and global communication strategies

There is need to develop global, regional and national communication strategies to allow effective communication of new information on fertilizer use and sustainable nutrient management to all relevant stakeholders. Support can also be provided through the design and development of responsive knowledge products targeting different audiences (e.g., policymakers, extension agents and farmers) and incorporating feedback loops.

11.3.5 The need for policy coherence

Conventions

Many international and regional initiatives are already contributing (or have the potential to contribute) to the reduction of pollution from fertilizers (Chapter 8.2-8.4). Increased collaboration among these initiatives would also contribute to reducing pollution. Conventions and policy instruments could work better together to address pollution from fertilizers by exploiting the synergies among them and with their partners. The implementation plan for the UNEP-led Towards a Pollution-Free Planet initiative (UNEP 2017) demonstrates how this can be done. It provides an overarching framework to address pollution in various dimensions (i.e., air, water, land/soil, marine and coastal pollution, and the cross-cutting issues of chemicals and waste), with Implementation to be achieved through collaborative efforts among different frameworks and players.

Nitrogen policies

Nitrogen policies and the SDGs are fragmented among different environmental domains (e.g., air pollution, freshwater and marine environments, health and food security). This fragmentation, which is also present in Multilateral Environmental Agreements (MEAs) (Sutton, Raghuram and Adhya 2019), has resulted in policy trade-offs. Nitrogen policies should therefore be brought together to take advantage of synergies among them, so as to speed up progress in addressing pollution. In addition, there is a need for an integrated approach in which nitrogen and phosphorus are considered jointly. Oenema (2019) suggests that including phosphorus initiatives in nitrogen discussions could be useful in the case of both nutrients. For example, both nitrogen and phosphorus contribute to pollution in the aquatic environment (Chapter 9.3.3) and can be recycled together (Chapter 7.2). A study by Kanter and Brownlie (2019) of 15 countries representing 75 per cent of both GHG emissions and nitrogen and phosphorus consumption concluded that a joint approach could be beneficial for all the national climate plans analysed and for the achievement of seven of the 17 SDGs. The authors also reported that

integration between science, policies and practice on this issue was lacking (as of 2018). Gu *et al*. (2018) argued that there it is crucial to take carbon sinks (which are necessary to reduce atmospheric carbon dioxide [CO_2] concentrations) into consideration when addressing nitrogen pollution, as large reductions of the latter may reduce the size of carbon sinks. They also suggested that this relationship should be included in global climate change modelling.

Efforts are already under way to bring together Multilateral Environmental Agreements (MEAs) with the potential to influence nitrogen pollution. For example, the Fourth Meeting of the International Nitrogen Management System (INMS-4) endorsed the proposal in the UNEA-4 nitrogen resolution to establish an Inter-convention Nitrogen Coordination Mechanism (Chapter 8.3.4) and identified the next steps (INMS 2019).

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