

Synthesis  
Report on the  
**Environmental  
and Health Impacts of  
Pesticides and Fertilizers  
and Ways to Minimize  
Them**

Envisioning  
a chemical-safe  
world



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ISBN No: 978-92-807-3929-9  
Job No: DTI/2427/GE

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Suggested citation: United Nations Environment Programme (2022). *Synthesis Report on the Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them*. Geneva.

Production: UNEP

URL: <https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/38409/pesticides.pdf>

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# Acknowledgements

The United Nations Environment Programme, Food and Agriculture Organization of the United Nations and World Health Organization wish to extend special thanks for the substantial contributions to the development and drafting of the report by Harold van der Valk and Lydia Wairegi, Achim Halpaap and Gamini Manuweera.

Further, technical review provided by Tapiwa Nxele and Mihaela Paun and substantial technical contributions on specific topics provided by Michiel Daam, Giorgia De Santis, Michael Eddleston, Javier Montero-Serrano, Evangelia Ntzani, Francesco Tubiello, Nathan Wanner, and Sirini Withana are greatly appreciated for their expertise, time, and commitment.

The report has been produced with generous financial contributions made by France and the European Union.

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The following persons kindly provided data, information and insights on technical aspects discussed in the report, drafted text, responded to surveys, or conducted reviews of parts of the text.

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Achim Halpaap, Agustin Harte, Yvonne Harz-Pitre, Charlotte Hebebrand, Patrick Heffer, Matthew Helmers, Ludwig Hermann, Alan Hill, Katerina Hora, Nguyen Thi Lien Huong, Ahmed Jaafari, Gillian Jackson, Jim Jenkins, Haosong Jiao, Erik Jørs, Abdelrahman M. Kamel, Mary Karalexi, Haekoo Kim, Donald Kitson, Monica Kobayashi, Hidetaka Kobayashi, Eva Kohlschmid, Irina Kovrova, Sandhya Kulshreshtha, Hugo Kupferschmidt, Amalia Laborde, Candace Laing, Diep Le, Annegaaïke Leopold, Jennifer Lewis, Xiaoqiong Li, Zili Lin, Xuejun Liu, Leslie London, Dave Lunn, Ewa Madey, Kaushik Majumdar, Chiara Manoli, Rorisang Mantutle, Gamini Manuweera, George Markozannes, Maricarmen Martínez, Cargele Masso, Javier Mateo-Sagasta, Yoshihiko Matsui, Hans Mattaar, Graham A. Matthews, Michael McLaughlin, Aleksandar Mihajlovski, Rob Mikkelsen, Pierre Mineau, Javier Montero-Serrano, Lara Moody, Christy Morrissey, David Mota-Sanchez, Marian Mraz, James Mutegi, Sophia Mylona.

Elizabeth Nambiro, Desiree Raquel Narvaez, Milcah Ndegwa, Christoph Neumann, Chirinda Ngonidzashe, Aiwerasia Vera Ngowi, Francis Kihumba Njuguna, Uraporn Nounart, Evangelia Ntzani, Michelle Nutting, Tapiwa Nxele, Carolina Olivera Sanchez, Peter Opiyo, Barron Joseph Orr, Sylvain Ouedraogo, Puneet Pachauri, Mihaela Paun, Paulo S. Pavinato, Jessica Phillips, Yongfan Piao, Gary Pierzinski, Rosa M. Poch, Anne-Sophie Poisot, Sylvie Poret, Mahesh Pradhan, Somchai Preechathaveekid, D'Arcy Quinn, Nandula Raghuram, Murari Mohan Rakshit, Rujuta Ranade, Pytrik Reidsma, Naima Rhalem, Jeannie Richards, Ngaio Richards, Juan Carlos Rios Bustamante, Evangelos Rizos, Natalia Rodriguez Eugenio, Jason RohrDanny Romney, Marilena Ronzan, Andrea Rother, Joseph Rusike.

Tania Santivanez, Tek Sapkota, Wataru Sasayama, Ivy Saunyama, Guilherme Schmitz, Victor Hugo Estellano Schulze, Saurabh Sehgal, Maxim Seregin, Kristin S. Shafer, Sheetal Sharma, Christian Sieke, Richard Sigman, Marina Simonova, Franklin Simtowe, John Smith, Jun Hua Song, Shirley Soto, Cindy Stephen, David Stewart, Jayakody A, Sumith and Will Surman, Christos Tagas, Elisabetta Tagliati, Sherif M. Taha, Win Than, Benedetta Tantalo, Jeimar Tapasco, Joanna Tempowski, Mechteld ter Horst, Youguo Tian, Yuxin Tong, Lilian Tornqvist, Mark Trimmer, Francesco Tubiello, Debra Turner, Keith Tyrell, Daisuke Uesako, Andrea Ulrich, Gero Vaagt, Clelia Vallebuona Stagno, Piet van Asten, Henk van den Berg, Paul van den Brink, Harold van der Valk, Falconsult, Carmen van Dijk, Bernard Vanlauwe, Ronald Vargas, Carolyn Vickers, David Wafula, Githaiga Wagate, Andrea Waichman, Lydia Wairegi, Andrew Ward, Donald Ward, Nathan Warner, James Watiti, Meriel Watts, Ajith G. Weerasundara, Stefan Weiler, Sherika Whitelocke-Ballingsingh, Stephanie Williamson, Sheila Willis, Sirini Withana, Lini Wollenberg, Lance Wormell, Rajpal Yadav, Yong Zhen Yang, Mario Yarto, Ritsuko Yoneda, Shanqui Yuan, Cunzheng Zhang, Fusuo Zhang, Xin Zhang, Yun Zhou, Liucai Zhu, Shamie Zingore, Hadjadj-Aoul Fatima Zohra, Jochen P. Zubrod, Maria Cristina Zucca.

# Executive Summary

In December 2017, the 3rd Session of the United Nations Environment Assembly by Resolution 3/4 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, the Food and Agriculture Organization of the United Nations and other relevant organizations by the fifth session of the United Nations Environment Assembly” (UNEP 2017a).

This report responds to the above mandate in UNEA Resolution 3/4 and presents a comprehensive review of available information on environmental and health effects and their potential impacts. The overall goal of the report is to provide a review of the information base and update the current knowledge to enable other advocacy actions to be taken by stakeholders to minimize the adverse impacts of pesticides and fertilizers. The report seeks 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; and identify opportunities to minimize environmental and health impacts, including proven and innovative approaches.

## ENVIRONMENTAL AND HEALTH IMPACTS

We live in a globalized world, where the needs and demands of a growing population and associated megatrends (e.g. urbanization and the growing global middle class) shape the production, trade and consumption of agricultural crops and other goods and services for which pesticides and fertilizers are used in significant quantities (UNEP 2019). The global demand for, and production and use of, pesticides and fertilizers have increased steadily during the past decades and are projected to continue growing (Oliver 2018; Food and Agriculture Organization of the United Nations [FAO] 2021a; International Fertilizer Association [IFA] 2021a). Unlike most industrial chemicals, pesticides and fertilizers (both inorganic and organic) are deliberately applied in the environment to provide desired functions. This creates potential risks to the environment and health.

A wealth of studies and reports address the adverse environmental and human health impacts of pesticides and fertilizers, with more information readily available on pesticides. The adverse impacts of pesticides are partly due to the fact that these chemicals are designed to be inherently toxic. While they are designed to eliminate unwanted insects, plants and other living organisms, they may also adversely affect non-target organisms (FAO and World Health Organization [WHO] 2014). In the case of fertilizers, adverse impacts mainly result from their release into the environment and their effects on ecosystems, which are largely due to nutrient loss through overuse or inefficient use (Sutton *et al.* 2013; FAO 2015; Kopittke *et al.* 2019).

## KNOWLEDGE GAPS

Despite many peer reviewed scientific studies, and the consolidated knowledge about the adverse impacts of pesticides and fertilizers at the global level brought by this report, there are still gaps in knowledge and information that need to be addressed.

On the environmental effects of pesticides, the report identified gaps in systematic reviews, environmental risk assessments and systematic monitoring. Regarding human health effects of pesticides, knowledge gaps identified relate to, among others, toxicological assessments (e.g. of co-formulants and of formulated products), toxicological evaluations (e.g. of complex human health outcomes), risk of combined effects from exposure to multiple active substances and lack of disaggregated data for potentially sensitive populations (e.g. female farmers and agricultural workers).

In addition, concerning pesticide management, no global review of the content and implementation of pest or pesticide management policies is currently available. Furthermore, large gaps still exist in the understanding of pesticides' ultimate environmental, health and economic impact under current conditions of use. Thus, informed decision-making about the best and most sustainable forms of pest and vector management, and the role of pesticides therein, is handicapped by lack of the comprehensive knowledge needed to develop sound national and regional policies.

While a key objective of governments is to improve people's health and welfare, their investment priorities may not include monitoring fertilizers' adverse impacts. There are large data gaps with respect to the knowledge on environmental effects and impacts of fertilizer use on human health and existing data are not disaggregated by gender, age or fertilizer type (i.e. organic compared to inorganic fertilizers). There are also gaps in information about the status of fertilizer policies at global, regional and national levels. In many cases, information on the progress made in implementing international and regional conventions at national level is not easily accessible to the public.

Furthermore, assessments of the global social costs of nutrient pollution are subject to many uncertainties (Sutton *et al.* 2013). Where data exist, it is difficult to compare the values of pollution costs from different studies. Various assumptions are made, for example in monetizing the different species of reactive nitrogen (Kanter, Zhang and Mauzerall 2014).



## OPTIONS FOR PRIORITY ACTIONS

The report presents options for action to reduce environmental and health risks and address identified knowledge gaps. These can be viewed as management reform actions. The priority actions are key conclusions identified through the overall evaluation and analysis undertaken. They present opportunities which focus on methodologies, tools, approaches and policies that directly strengthen pesticide and fertilizer management:

### Priority actions to strengthen pesticide management

- ❖ Strengthen control of pesticide distribution and use and enforcement of relevant legislation;
- ❖ Scale up development of both new and existing international pesticide evaluations;
- ❖ Minimize or eliminate the risks posed by Highly Hazardous Pesticides;
- ❖ Strengthen post-registration monitoring of pesticides and their effects;
- ❖ Prioritize development of and access to low-risk pesticides and bioprotectants;
- ❖ Address the trade in substandard, illegal and counterfeit pesticides;
- ❖ Support adoption of extended product responsibility by all pesticide manufacturers and traders.

### Priority actions to strengthen fertilizer and nutrient management

- ❖ Ensure comprehensive national policies for quality control of fertilizers;
- ❖ Fill information and knowledge gaps for effective fertilizer and nutrient management;
- ❖ Strengthen policies globally to support sustainable and safe use of fertilizers;
- ❖ Scale up training of all relevant stakeholders in fertilizer and nutrient management;
- ❖ Ensure that suitable and affordable fertilizers are accessible, particularly in low and middle income countries.

### Priority transformative actions to strengthen pesticide and fertilizer management

The report also presents transformative actions to fundamentally change how pesticides and fertilizers are produced, used and managed through concerted action by a wide range of stakeholders in the agri-food system and in value chains (e.g. consumers, the agricultural inputs industry, the food industry, farmers' associations, agricultural research institutions and policymakers). These transformative actions were identified through consultations with government experts, independent scientists, experts from intergovernmental organizations, and other stakeholders from the public and private sector:

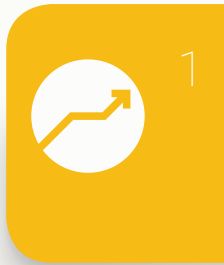
- ❖ Incentivize healthy and sustainable consumer choices and consumption;
- ❖ Fundamentally change crop management and adopt ecosystem-based approaches;
- ❖ Promote circularity and resource efficiency;
- ❖ Use economic instruments to create a level playing field for greener products and approaches;
- ❖ Adopt integrated and life cycle approaches for sound pesticide and fertilizer management;
- ❖ Strengthen standards and adopt corporate policies for sustainable supply chain management.

1 In this report the term billion is defined based on the short scale as one thousand million or 10<sup>9</sup> (ten to the ninth power).





## KEY FINDINGS



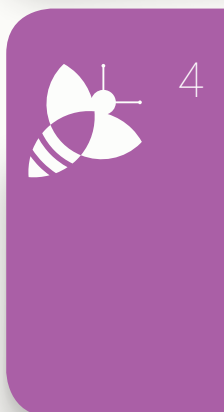
1 Global demand, production and use of pesticides and fertilizers have expanded steadily during the past decades (Oliver 2018; FAO 2021a; IFA 2021a). Combined global sales values continue to grow at about 4.1 per cent per year and are projected to reach United States dollars (USD) 309 billion<sup>1</sup> by 2025 (Grand View Research 2017).



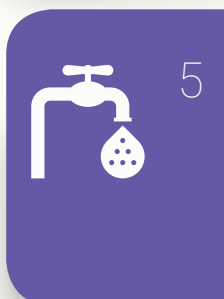
2 Demand for food, hence crops, goods and services is fuelling the production and use of pesticides and fertilizers (Bodirsky *et al.* 2015; Organisation for Economic Co-operation and Development and FAO 2018). Demand for crops used for animal feed, fibres, fuels and feedstocks is also growing (International Feed Industry Federation [IFIF] 2021).



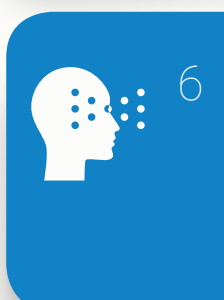
3 Positive associations between exposure to pesticides and certain health outcomes have been established, including acute and long-term effects (Prüss-Ustün *et al.* 2016; Ntzani *et al.* 2020). About 385 million cases of unintentional acute pesticide poisonings have been estimated to occur every year, with approximately 11,000 deaths (Boedeker *et al.* 2020).



4 Pesticides and their degradation products are ubiquitous in the environment, including soils, sediments and surface and groundwater, often detected at levels exceeding environmental standards or guidelines leading to serious environmental as well as health impacts (Vulliet *et al.* 2014; Elibariki and Maguta 2017; Guida *et al.* 2018; Hvězdová *et al.* 2018; Pietrzak *et al.* 2019). Adverse impacts of pesticides have been observed on bees and natural enemies of pests, bird populations, aquatic organisms, and biodiversity (Cloyd 2012; Roubos, Rodriguez-Saona and Isaacs 2014; Kovács-Hostyánszki *et al.* 2016; Tassin de Montaigu and Goulson 2020; Sánchez-Bayo and Wyckhuys 2019)



5 Adverse impacts of fertilizers are mainly caused by their excessive and inefficient use resulting in nutrient losses to the environment, drinking water contamination and eutrophication of freshwater systems and coastal zones (Sutton *et al.* 2013; FAO 2015; Kopittke *et al.* 2019). Some fertilizers also impact human lives as a result of unsafe storage practices (Pittman *et al.* 2014) and the growth of toxic algae in nutrient rich waterways (Kubickova *et al.* 2019; Chorus and Walker 2021).



6 Knowledge gaps still exist that hamper a full understanding of some of the mechanisms and processes leading to the adverse impacts of pesticides and fertilizers, together with the effectiveness of some control measures. Attention to the establishment of sustainable mechanisms for the collation and regular review of existing data on manufacture, sales, use, environmental concentrations and impacts is required.

To achieve a chemical-safe future with minimal adverse impacts from pesticides and fertilizers, actions are required in both the sound management of pesticides and fertilizers as well as the transition to safer and greener alternative solutions. These should enable to tackle root causes and shift market demand, coupled with supportive and enabling measures. Further, a set of transformative actions to minimize the adverse impacts of pesticide and fertilizers were identified through consultations with government experts, independent scientists, experts from intergovernmental organizations, and other stakeholders from the public and private sector.

Identification of these transformative actions are based on the impact they are expected to have on the sustainability of pesticide and fertilizer use, the degree to which they would minimize adverse impacts, and their interconnection with the Sustainable Development Goals (SDGs) and associated global policies.

Details on these options for action are presented in Sections 5 and 6.

While stakeholders in the value chain and agri-food system are contributing to minimize adverse effects of pesticides and fertilizers, there is further need to scale up their commitment.

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## Background

Pesticides and fertilizers – both inorganic and organic – are deliberately applied in the environment to improve food security, social qualities and services which can result in risks to the environment and human health. Despite the large number of published scientific studies on the environmental and health impacts of pesticides and fertilizers, data gaps remain and there is a lack of consolidated knowledge about their impacts at the global level.

In 2017 the third United Nations Environment Assembly (UNEA-3) requested the Executive Director of UNEP in Resolution 3/4 “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” (UNEP 2017a).

Subsequently UNEP developed the *Report on the Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them*, in collaboration with FAO, WHO, and a wide range of other experts and stakeholders. Between late 2018 and mid-2020 a number of physical and online consultations took place with experts on pesticides and fertilizers including the Joint FAO/WHO Joint Meeting on Pesticide Management, specialists from intergovernmental and non-governmental organizations and the

private sector, and policymakers from countries in different regions.

A comprehensive compilation of scientific information about the adverse impacts of pesticides and fertilizers and ways to minimize them is available online as complementary background information.<sup>2</sup> Data and information are provided on global use patterns, along with policy and regulatory frameworks that address manufacture, distribution and use. In addition to presenting the prevailing scientific understanding of the environmental and health impacts of pesticides and fertilizers, the report also identifies important knowledge gaps.

A Summary for Policymakers was published in 2021.<sup>3</sup> It sets out the main findings of the comprehensive compilation in a concise form, together with options for priority actions that can be taken by policymakers and other stakeholders to minimize the adverse impacts of pesticides and fertilizers.

- 2 To access the comprehensive compilation of scientific information please visit** <https://www.unep.org/resources/report/environmental-and-health-impacts-pesticides-and-fertilizers-and-ways-minimizing>
- 3 The Summary for Policymakers is available online in English with translations into Arabic, French, Russian and Spanish. A Chinese version is forthcoming.** <https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/34463/JSUNEPFF.pdf?sequence=13>

This Synthesis Report outlines key findings; global drivers, actors and policies shaping the use of pesticides and fertilizers (Section 2); Adverse environmental and health impacts of pesticides and fertilizers (Section 3); Social and economic impacts of pesticides and fertilizers (Section 4); Options for minimizing the adverse impacts of pesticides and fertilizers (Section 5); and Transformative actions to minimize the adverse impacts of pesticides and fertilizers (Section 6). In this synthesis report, any reference to “chapters” signifies the corresponding background information, while any reference to “sections” represents the contents of the synthesis report.

Figure 1 indicates the chapters of the comprehensive compilation of scientific information that are especially relevant with respect to the drivers, information gaps, effects and impacts, and options for priority actions listed in the figure. The key findings and options for actions presented in this Synthesis Report are informed by the large amount of information about the environmental and health impacts of pesticides and fertilizers in the comprehensive compilation. They are based on analyses carried out during the preparation of the comprehensive compilation of scientific information, as well as consultations with national experts and major stakeholders.

4 In this synthesis report, any reference to “Chapters” signifies the corresponding background information.

► **Figure 1 Drivers, information gaps, effects and impacts, and options for priority actions identified in the Report on the Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them (P = pesticides; F = fertilizers)<sup>4</sup>**

**Drivers**  
Chapters 2 (P) and 7 (F)

- ▶ Global demand, production and use have expanded steadily in the past decades.
- ▶ Pesticides and fertilizers provide a range of benefits, but current and projected use combined with a lack of effective management have adverse impacts on the environment and human health throughout their life cycles.

**Information gaps**  
Chapters 3 (P) and 8 (F)

- ▶ Knowledge gaps still exist. Nevertheless, available evidence provides sufficient justification for additional actions.
- ▶ Progress has been made in strengthening the management of pesticides and fertilizers, but not all adverse environmental and health impacts are being addressed comprehensively.

**Effects and impacts**  
Chapters 4, 5 (P) and 9, 10 (F)

- ▶ Pesticides have both acute and long-term health impacts.
- ▶ Pesticides and their degradation products are ubiquitous in the environment.
- ▶ Adverse impacts of fertilizers are mainly caused by their excessive and inefficient use. This leads to nutrient losses to the environment and other adverse impacts.

**Business-as-usual**

**Contributes to the planetary and human crisis caused by unsustainable patterns of consumption and production.**

**Options for priority actions**  
Chapters 6 (P), 11 (F) and 12 (P+F)

- ▶ Both incremental and transformative actions are required by stakeholders in the value chain and the agri-food system to achieve a chemical-safe future with minimal impacts.
- ▶ There is a further need to scale up commitments by stakeholders in the value chain and agri-food system, using targets and road maps.

*The global goal to minimize adverse impacts of chemicals and waste by 2020 has not been achieved for pesticides and fertilizers*

*Business-as-usual is not an option*



# Global drivers, actors and policies shaping the use of pesticides and fertilizers

2

## Global drivers that affect demand for pesticides and fertilizers<sup>5</sup>

By 2050 global demand for food is projected to increase by 60 per cent, meat production by nearly 70 per cent, aquaculture production by 90 per cent, and production of dairy products by 55 per cent (IFIF 2021). At the same time, cropland is increasingly used for non-food purposes such as production of livestock feed, fibres, biofuels, and chemical industry feedstocks (Data Bridge Market Research 2020; Statista 2021; Grandview Research 2021).

Intensification of agricultural production is partly achieved through higher use of pesticides and fertilizers. Between 2002 and 2018 the global population increased by about 21 per cent (FAO 2020a) and cereal production by about 44 per cent (FAO 2020b). In the same period, pesticide use per hectare of cropland increased by about 30 per cent (FAO 2021a) and inorganic fertilizer use per hectare increased by about 23 per cent for nitrogen, 13 per cent for phosphorus and 56 per cent for potassium (FAO 2020c).

Use of voluntary sustainability standards in the agriculture sector is expanding (Elamin and Fernandez de Cordoba 2020; International Trade Centre 2021; United Nations Forum on

Sustainability Standards 2021). However, only about 1 per cent of total agricultural cropland globally is estimated to have been certified between 2000 and 2011 (Taylour *et al.* 2017) (see Chapter 1).

## Drivers of pesticide use

Many drivers influence the use of pesticides in agriculture and for public health and domestic purposes. Drivers likely to increase their use include agricultural intensification, the occurrence of pests, pesticide resistance, the presence of genetically modified herbicide tolerant crops, marketing practices, and commodity prices. Drivers that tend to reduce pesticide use include integrated pest management (IPM) and crop rotation. The extent to which particular drivers influence pesticide use is heavily influenced by local agronomic, regulatory, economic and social conditions (see Chapter 2.7).

## Drivers of fertilizer use

Drivers of fertilizer use exist at farm level and beyond the farm. They can be technological, associated with consumers, or related to sustainability aims. Some drivers encourage increased use of fertilizers, but others minimize excessive use or discourage it altogether. Some drivers can have either effect, depending on the circumstances (see Chapter 7.5).

<sup>5</sup> Chapter numbers in brackets refer to the corresponding background information.

The drivers of fertilizer use include:

- ▶ policies, subsidies and government support;
- ▶ marketing strategies, credit and markets for produce, and use of information and communications technology (ICT);
- ▶ health and environmental concerns, including those reflected in policies and regulations;
- ▶ soil degradation;
- ▶ integrated soil fertility management and other approaches to increase production and input use efficiency;
- ▶ adoption of crop varieties, approaches and technologies that increase fertilizer use efficiency;
- ▶ supply (availability of inputs) and infrastructure;
- ▶ access to information, social networks, and membership in cooperatives;
- ▶ climate change.

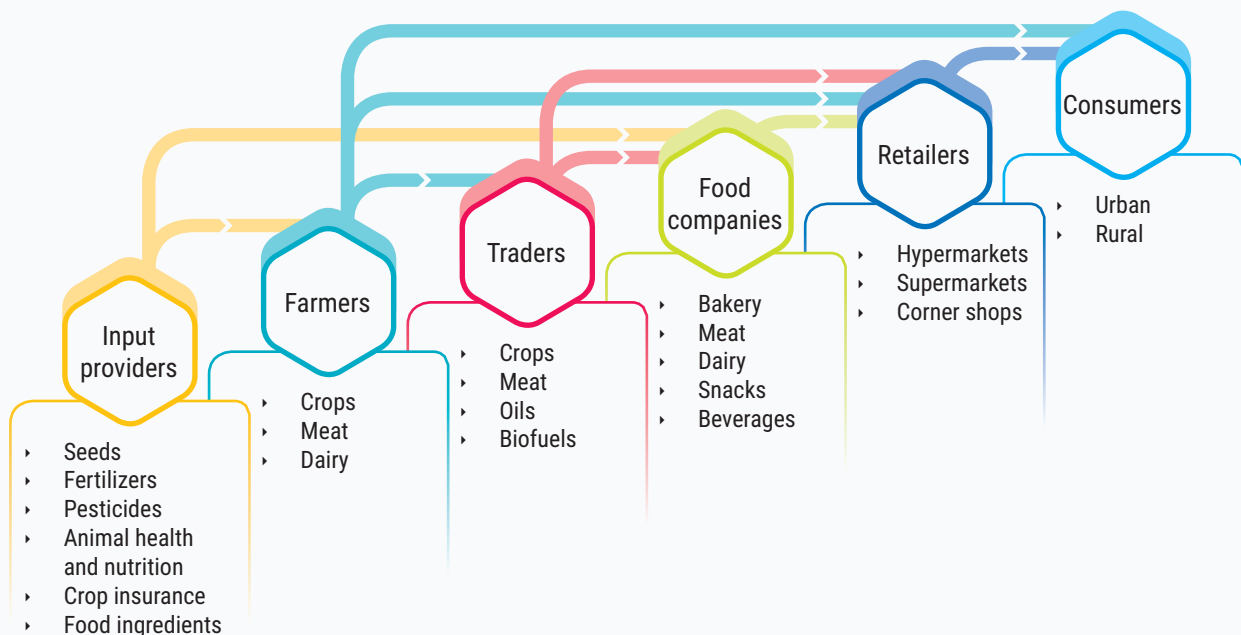
### Global actors in the value chain affecting pesticides and fertilizer demand

The production and use of pesticides and fertilizers are affected by diverse actors in the value chain of the global agri-food system and in other, non-agricultural value chains. They include consumers, farmers, the pesticide and fertilizer industries, and other corporate actors including retailers, food companies and textile companies. The report notes that the global agri-food market is now controlled by a small number of corporations.

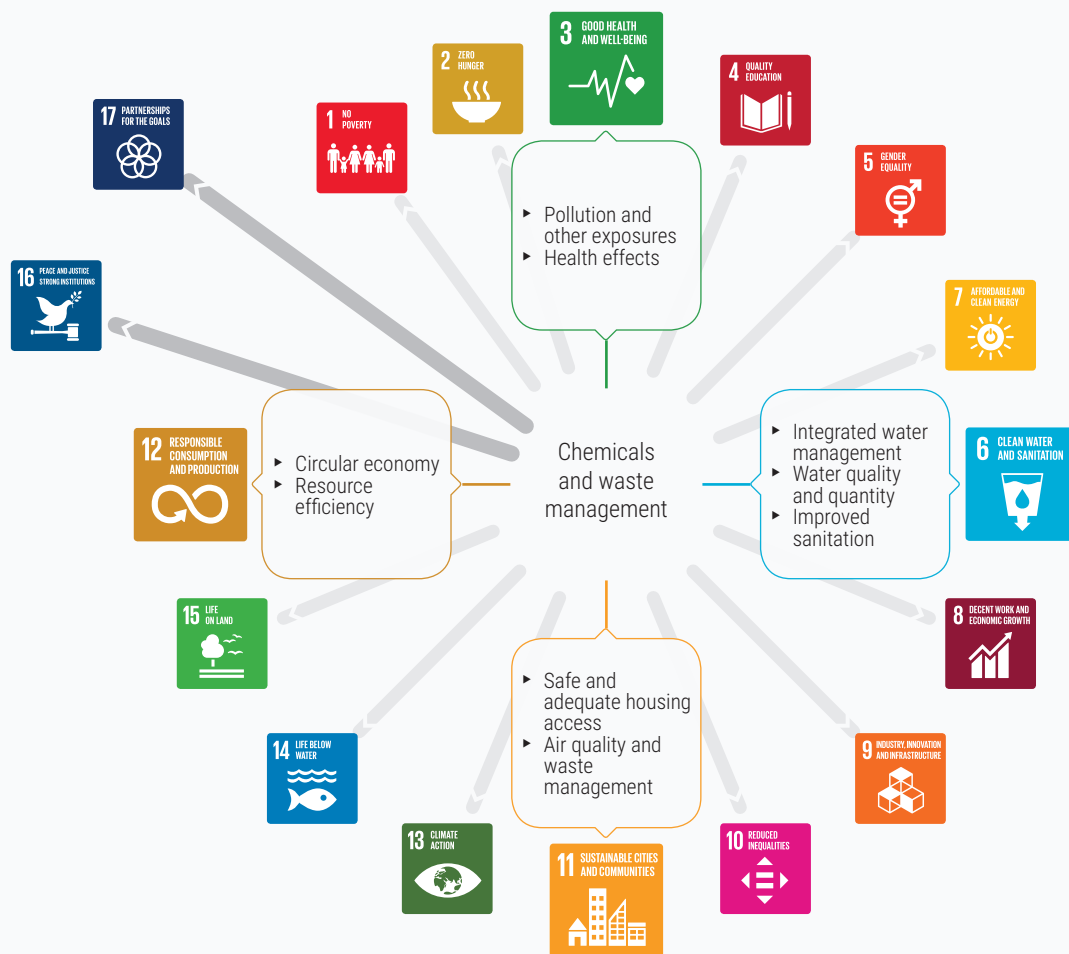
Figure 2 is an overview of the agriculture and food value chain, from input companies (including pesticide and fertilizer producers) to consumers.

Access to pesticides and fertilizers, as well as knowledge about their proper use and the possibility to use certain technologies, are determined by users' socioeconomic status, their geographic location, and the policies and regulatory processes in place. The ways pesticides and fertilizers are used (with impacts on the environment and health) greatly differ between, for example, smallholder and industrial scale farming. Risk reduction measures at all levels should take into account the conditions associated with agriculture at different scales.

▶ Figure 2 The agriculture and food value chain



► **Figure 3 Linkages between chemicals and waste and the Sustainable Development Goals.** Based on Inter-Organization Programme for the Sound Management of Chemicals (IOMC) (2018), p. 3.



Implementation of the Sustainable Development Goals (SDGs) presents an opportunity for collaborative action among diverse actors at all levels to minimize the adverse impacts of pesticides and fertilizers. Several SDGs are directly relevant to the sound management of chemicals and waste (Figure 3). For example, under SDG 12, “Ensure sustainable consumption and production patterns”, Target 12.4 calls for achieving the environmentally sound management of chemicals and all wastes throughout their life cycle by 2020. (This goal has not yet been met.) Under SDG 3, “Ensure healthy lives and promote well-being for all at all ages”, Target 3.9 calls for substantially reducing the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination by 2030 (see Chapter 1).

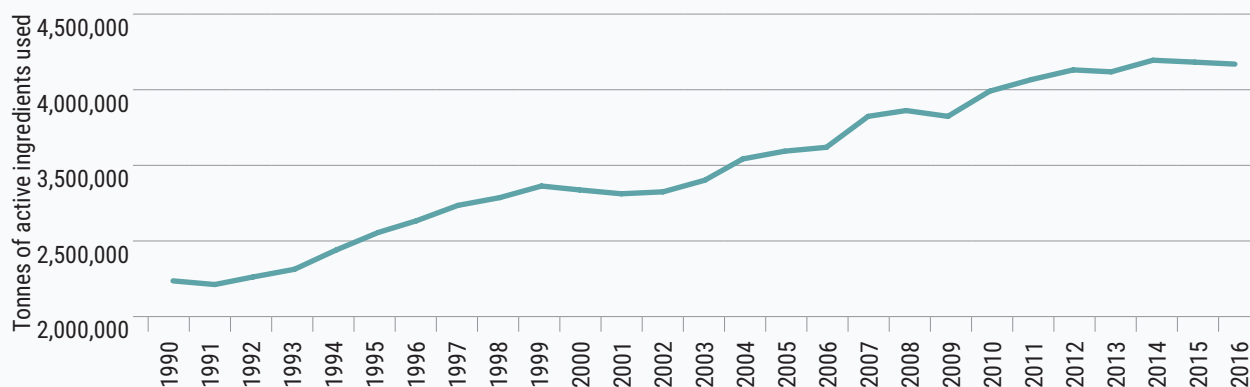
## 2.1 Pesticides

### The sale and use of pesticides

Global pesticide use has continued to increase in the past decades in terms of total volumes used (Figure 4) and amounts applied per hectare of cropland. However, pesticide use per unit crop output has remained unchanged (FAO 2021a). This indicates that pesticide use efficiency has not improved at the global level even though modern pesticides are more biologically active per gram of active ingredient applied.

The majority of pesticides are used in agriculture. Non-crop uses (e.g. disease vector control or domestic, amenity and industrial applications) represent only about 10-15 per cent of the global

► **Figure 4 Global use of pesticides in agriculture increased from about 2.3 million tons of active ingredient in the early 1990s to more than 4 million tons in 2016.**<sup>6</sup> FAO (2019a).



market by value (Agrow 2019). Products used for these purposes tend to be applied in or near human habitations. Therefore, they pose different (and sometimes higher) risks than agricultural pesticides. Such uses represent a small share of the total market; nevertheless, their environmental and health impacts are of concern since the pesticides involved are often applied by untrained non-professionals including homeowners. While both the sales and uses of agricultural pesticides are relatively well monitored, much less is known about the uses of non-agricultural pesticides.

Bioprotectants, also referred to as biological pest control agents, are products that originate from nature. Most are formulated as biopesticides. The global market for biopesticides is projected to grow significantly (Glare *et al.* 2012; Dunham-Trimmer 2019). The rate of introduction and authorization of new biopesticides has already exceeded that of new conventional pesticides in some cases – a trend which appears likely to continue (Robin and Marchand 2018) (see Chapter 2.4).

### Pesticide distribution mechanisms

A variety of pesticide supply chains exist, often operating in parallel within a country or region (Figure 5). Pesticide distribution companies (both national and international) import and distribute commercial pesticide products in one or more countries. Pesticides are sold to

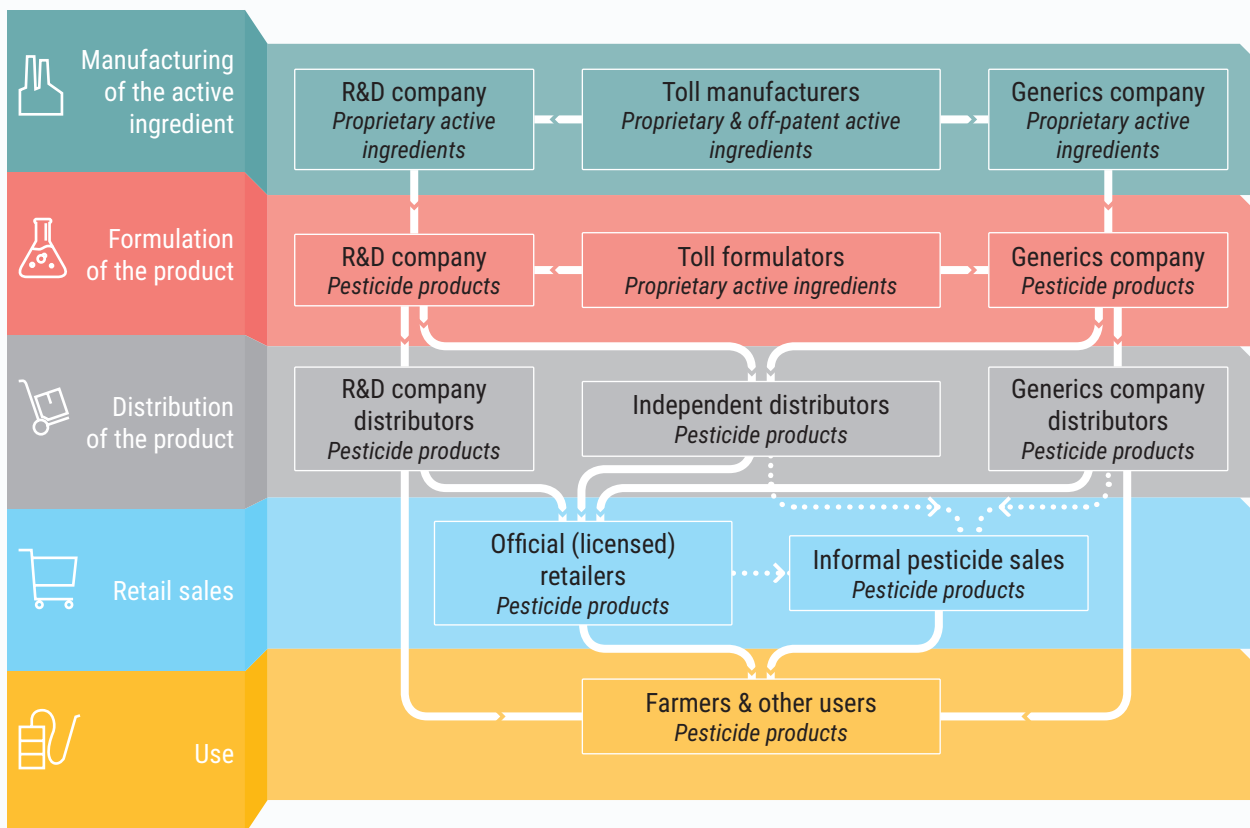
users by retailers ranging from shops or dealers specialized in agricultural inputs, to supermarkets, household, garden and do-it-yourself retailers and general retail outlets, to markets and travelling pesticide sellers.

A small number of corporations control important segments of the global agri-food market. For example, four (conglomerates of) companies currently represent about 65 per cent of the global pesticide market (Bellmann, Lee and Hepburn 2019). Companies that produce pesticides often have important activities in the areas of seeds and biotech crops, leading to a concentration of research, development and marketing capacities with respect to agricultural inputs.

Growth of the global pesticide market has been accompanied by increased trade of illegal pesticides, including those that are banned or otherwise non-authorized, counterfeit, fake, and illegally labelled or packaged (GRID-Arendal 2020; European Parliament 2020; CropLife International 2021). Illegal pesticides can damage crops, contaminate the environment and harm human health. The trade in illegal pesticides is difficult to quantify owing to its nature. Recent estimates indicate that, depending on the country or region, illegal pesticides represent between 10 and 25 per cent of national pesticide markets, with even higher estimates in some countries (European Parliament 2020; UNEP and GRID-Arendal 2020) (see Chapter 2.5).

6 In this report tons means metric tons.

► Figure 5 Simplified pesticides supply chain, where pesticide products may originate from different sources



### International instruments that address pesticide distribution and use

A number of international instruments and mechanisms address one or more aspects of the life cycle of pesticides. Some are legally binding, while others are voluntary. Some directly address pesticide management, production, distribution and use; others provide a more general policy context in which pesticide use and management are addressed more indirectly (Figure 6).

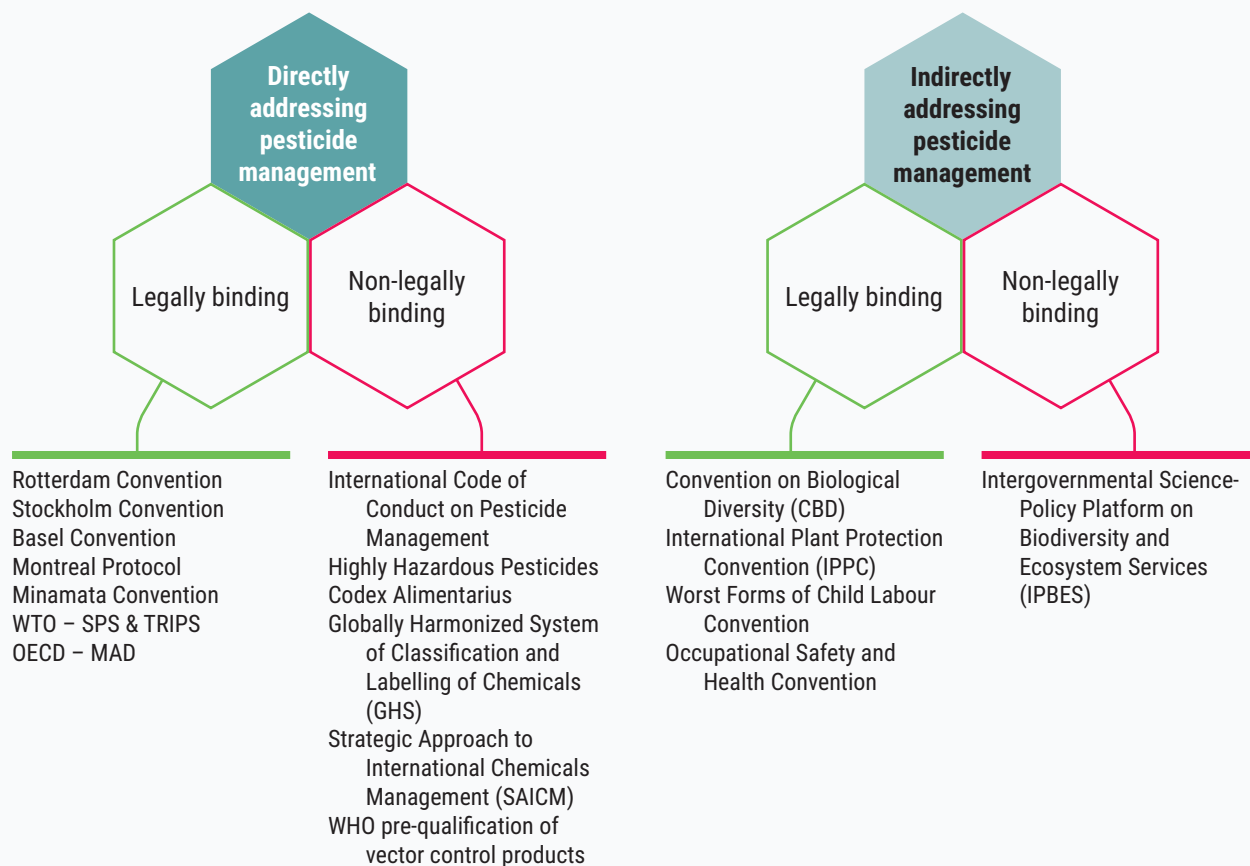
A challenge in regard to many legally binding and voluntary international instruments or mechanisms is that their impacts on pesticide risk reduction cannot be well evaluated. Indicators and procedures that might allow such evaluation are inadequate, partly because these instruments or mechanisms may focus on specific aspects of broader pesticide or chemical risk reduction.

In the case of the Rotterdam Convention, for example, no reviews have been conducted

to assess whether the pesticides listed in the Convention's Annex III are used and managed more judiciously by Parties to the Convention after they are listed. Nevertheless, the principal activity under the Convention is information exchange on chemicals and their risks. In an evaluation conducted by the Convention's Secretariat to assess whether listing a chemical in Annex III had led to an increase in notifications of bans or severe restrictions, no increase in the number of notifications of bans or restrictions was observed (Rotterdam Convention 2017). Another study, by the European Commission (EC), assessed the effects on trade volumes and prices of listing four pesticides (alachlor, aldicarb, monocrotophos and parathion). This study found no conclusive evidence that an impact on trade resulted from listing any of these pesticides (EC 2017).

The absence of broader impact assessments makes it difficult to quantify the extent to which international instruments and mechanisms contribute to reducing the risks posed by

► **Figure 6 Key international instruments and mechanisms which address pesticide management and use, either directly or indirectly. Conventions are listed only if they have been ratified by more than 50 countries.** Adapted from FAO and WHO (2014).



Note: Conventions are only listed if they are ratified by more than 50 countries.

pesticides (or by chemicals in general) (see Chapter 3.2).

### Regional collaboration on pesticide management

Regional collaboration on pesticide management can take various forms, ranging from simple information exchange mechanisms to more complex systems for shared decision-making. Carrying out activities such as evaluation, authorization, inspection and control of pesticides at the regional level can often optimize the use of limited human and financial resources and strengthen regulatory potential since a larger geographical area is covered. Because borders in many parts of the world are relatively porous, regional collaboration may increase the possibilities to control cross-border (illegal) trade in pesticides. Regional harmonization of registration

requirements can also facilitate registration of new (lower risk) pesticide products, which would be more expensive for one country to carry out alone.

Many regional pesticide management initiatives have been initiated, ranging from harmonization of pesticide testing protocols and pesticide management action plans to pesticide registration. A number of such regional initiatives have been actively supported by FAO and WHO, especially in low- and lower-middle-income countries (see Chapter 3.3).

### National policies and legislation on pesticides

No global reviews assessing the content and quality of pesticide legislation are available, nor is there any systematic analysis of legal gaps. However, international guidance on the elaboration and content of pesticide legislation is available

with which to assess the comprehensiveness of national pesticide legislation (FAO and WHO 2020).

The FAO/WHO International Code of Conduct on Pesticide Management (FAO and WHO 2014) recommends that countries regulate pesticides taking into consideration all stages of the pesticide life cycle. In principle, pesticide legislation should cover all types of pesticides and all stages of their life cycle. In many countries various stages of the pesticide life cycle are regulated through dedicated pesticide legislation, which often includes authorization, importation, storage and transport, distribution and sales, licensing, labelling and use. Other stages such as manufacturing and formulation (to which environmental and health standards are applicable) or disposal may be regulated under other legislation.

All high-income countries have dedicated pesticide legislation in place. Some 92 per cent of the remaining countries regulate (some groups of) pesticides (FAO and WHO 2019). However, pesticide legislation does not necessarily cover all stages of their life cycle.

In the majority of countries there are pesticide registration systems in place for the evaluation of pesticide products and authorization of their use. Especially in low- and lower-middle-income countries, human resources for the sound evaluation of pesticides are very limited while assessing their efficacy, hazards and risks is becoming increasingly complex (FAO and WHO 2019).

Government inspection and control of pesticide related activities are essential if national pesticide legislation is to be implemented effectively. Nevertheless, enforcement capacity is generally considered weak in many countries, often due to limited resources (FAO and WHO 2019).

National standards (e.g. for pesticide labelling and packaging or the use of personal protective equipment when applying pesticides) directly affect pesticide sales and use (FAO and WHO 2020). At the same time, pesticide management is cross-sectoral in nature. The ways pesticides are authorized, managed and used can be influenced not only by dedicated pesticide

legislation, but also by laws, regulations and standards elaborated in other sectors. Legislation on environmental protection, public health, occupational health, water, food safety, plant protection, general chemicals management, and transport and disposal of hazardous substances may all be relevant. For example, legislation aimed at environmental protection may include requirements concerning the siting and construction of pesticide formulation plants or sales outlets, but may also establish surface water standards that need to be taken into account when a pesticide is registered; food safety legislation may define pesticide maximum residue limits which influence both the authorization of pesticides and good plant protection practices to be followed by farmers; and occupational health legislation may include requirements for the protection of workers who apply pesticides or harvest crops.

In the last two decades several European countries have adopted pesticide use or pesticide risk reduction policies (Danish Environmental Protection Agency 2017; Government of France 2018; EC 2020). Stand-alone pesticide management policies are much less common in other parts of the world, where pesticide management policy elements may be incorporated in more general pesticide legislation.

No global review of the content and implementation of countries' pest or pesticide management policies is currently available. Globally, the adoption of policies specifically aimed at pesticide management has been rare so far. A comprehensive national pest/vector and pesticide management policy, adopted by all the main stakeholders, would constitute an important first step towards achieving the goal of pesticide risk reduction (see Chapter 3.4).

### Corporate stewardship

Within the framework of pesticide management, product stewardship is defined in the International Code of Conduct on Pesticide Management as "responsible and ethical management of a pesticide product from its discovery through to its ultimate use and beyond" (FAO and WHO 2014). This definition explicitly recognizes that product

stewardship is needed throughout a pesticide's life cycle.

Product stewardship is practised by individual pesticide companies and industry associations. In the private sector product stewardship is essential to ensure the optimal cost-efficacy of the pesticides being sold, as well as to minimize environmental and health risks before, during and after use. Extended producer responsibility (EPR) for post-use aspects (e.g. empty container management, or prevention and disposal of pesticide waste) contributes to the development of a circular economy.

Pesticide manufacturers, distributors and retailers have a primary responsibility to minimize adverse impacts. However, pesticide product stewardship can be practised not only within the pesticide industry, but also by the food and commodity industries and major pesticide users (see Chapter 3.5).

## 2.2 Fertilizers

### Fertilizer demand, sales and use

Global demand for inorganic fertilizers is forecast to reach about 208 Mt nutrients in 2025/2026, compared with around 187 Mt in 2018/2019 and 198 MT in 2020/2021 (IFA 2021a). The volume of organic fertilizers applied in the world and their monetary value are undocumented.

Global sales revenues for inorganic fertilizers in 2018 were reported to be about USD 151 billion; the global fertilizer market has been projected to grow at a compound annual growth rate (CAGR) of 3.8 per cent in the period 2020-2025 (Ilinova, Dmitrieva and Kraslawski 2021) (see Chapter 7.3).

### Fertilizer use and supply by regions

Figure 7 shows the estimated amounts of nutrients from inorganic fertilizer (nitrogen, phosphorous and potassium) used in agriculture globally between 2002 and 2017, by regions. In this period the total amount of nitrogen, phosphorus

and potassium used globally for agricultural purposes increased from 140 Mt to 190 Mt of nutrients (FAO 2020d) and the amount of inorganic fertilizer used per hectare increased by about 23 per cent for nitrogen, 13 per cent for phosphorus and 56 per cent for potassium (FAO 2020c).

Asia is the largest consumer of nitrogen, phosphorus and potassium from inorganic fertilizers, while Oceania and Africa consume the least. Latin America is expected to be the main contributor to global growth in the medium term and Africa is expected to be the fastest growing market (IFA 2021a).

Asia is the world's largest supplier of nitrogen and phosphorus; North America and Eastern Europe and Central Asia (EECA) are the largest potassium suppliers (IFA 2019). Between 2019 and 2023 phosphorus production is expected to increase in Africa, Latin America, West Asia and South Asia while potassium production is expected to increase in Canada, China, and Eastern Europe and Central Asia (EECA) (IFA 2019) (see Chapters 7.3.1 and 7.3.2).

### Fertilizer distribution and sales mechanisms

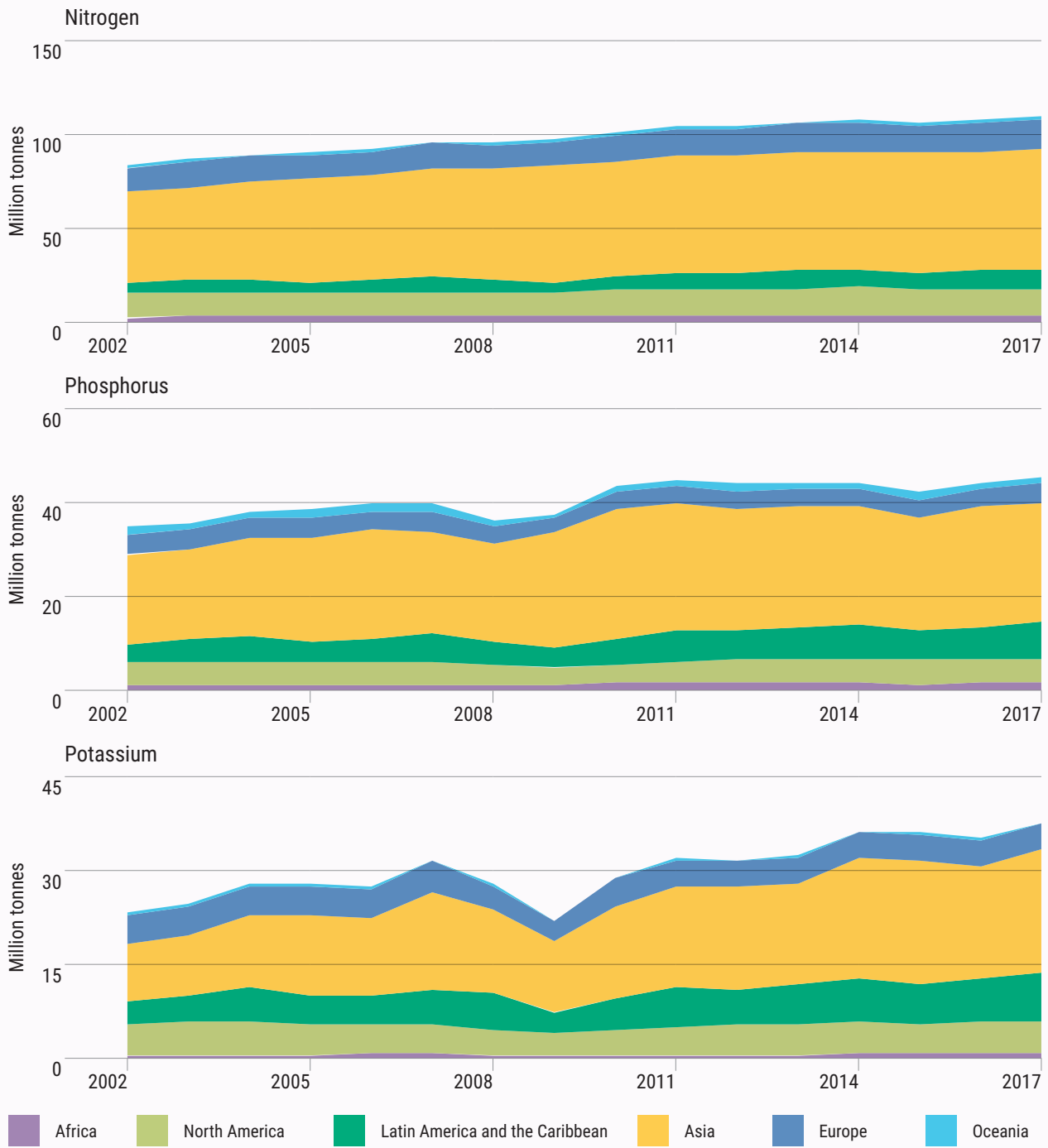
The organic fertilizer supply chain can be shorter than that of inorganic fertilizers, for example where farmers recycle products generated on their own farms or purchase products such as manure from neighbouring farmers.

Globally the inorganic fertilizer industry is largely represented by the International Fertilizer Association (IFA 2021b). In 2020 there were over 400 members in 70 countries. IFA members represent different sectors of the industry. The organic fertilizer industry does not have a global association. The lack of such an association for the organic fertilizer industry could be due in part to its traditionally local nature (with respect to both raw materials and markets) and the fact that most producers are small and medium-sized enterprises.

Distribution costs tend to be high in landlocked countries, partly because of additional transport



► **Figure 7 Nitrogen (N), phosphorus (P<sub>2</sub>O<sub>5</sub>) and potassium (K<sub>2</sub>O) fertilizer use in agriculture (Mt), 2002-2017.**  
FAO (2020a).

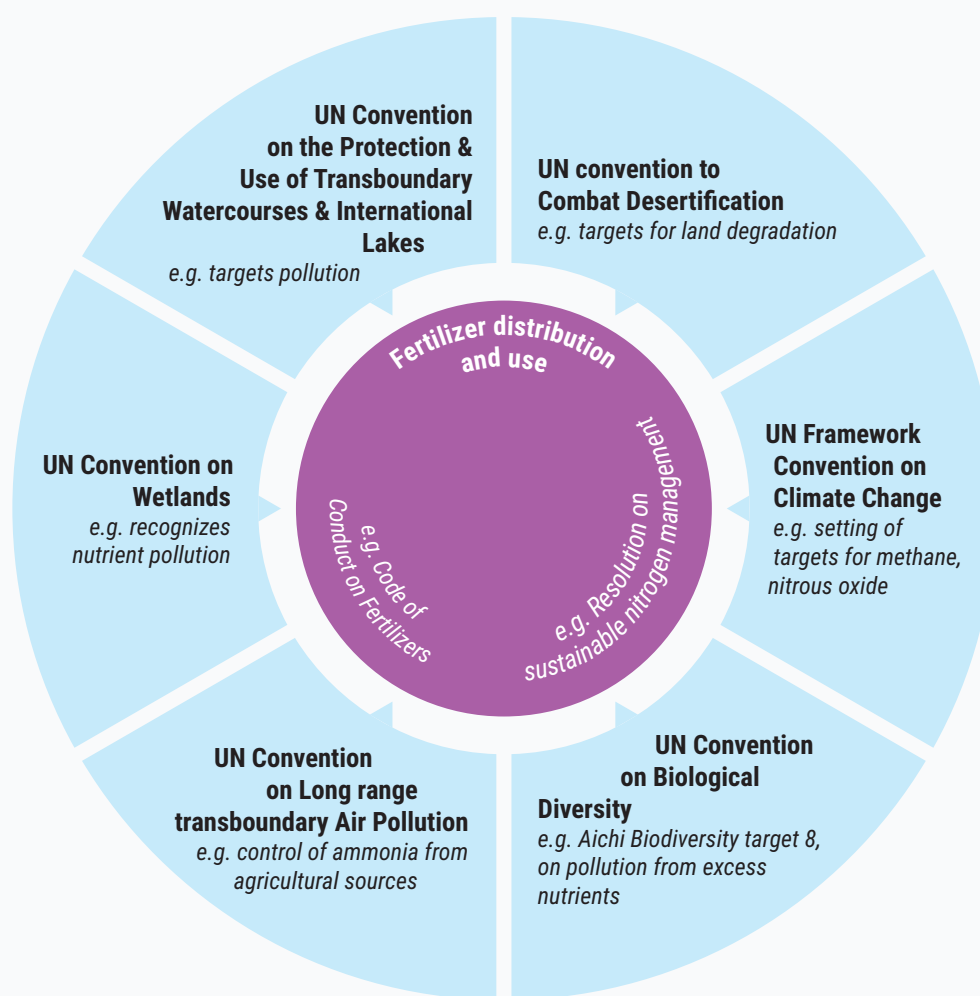


costs (Wanzala and Groot 2013). In sub-Saharan Africa a large portion of retail costs are for transport, as fertilizer is mostly carried by road within countries and through the continent (Cedrez *et al.* 2020) (see Chapter 7.4).

#### International instruments that address fertilizer distribution and use

The main international Conventions with the potential to influence fertilizer distribution and use are shown in Figure 8. In addition, guidance on the safe transport and storage of potentially

► Figure 8 International Conventions with potential to influence fertilizer distribution and use



explosive fertilizers is provided by the United Nations Economic Commission for Europe (UNECE) Convention on the Transboundary Effects of Industrial Accidents (the Industrial Accidents Convention).

The FAO International Code of Conduct for the Sustainable Use and Management of Fertilizers (the Fertilizer Code) (FAO 2019a) promotes practices that encourage judicious use of fertilizers. The stakeholders addressed include governments, policymakers, researchers, academia, farmers and the private sector. The Fertilizer Code emphasizes the importance of capacity development and educational programmes for all stakeholders along the fertilizer value chain. It also encourages high-income countries to assist other countries in developing infrastructures and the capacity to manage fertilizers throughout their life cycle.

Several international organizations, partnerships and initiatives have the potential to influence fertilizer distribution and use at the global and regional levels. They include the Global Soil Partnership (GSP) (FAO 2020d; FAO 2021b), the Global Partnership on Nutrient Management (GPNM) (GPNM 2014; UNEP 2021a), the International Nitrogen Initiative (INI) (INI 2020) and the World Trade Organization (WTO).

Under the GSP there are seven Regional Soil Partnerships (RSPs) covering Africa, Asia, Europe, Latin America and the Caribbean, the Pacific, the Near East and North Africa, and North America. The RSPs build on existing regional networks or collaborative processes and provide guidance with respect to regional goals/priorities and their required implementation mechanisms. They work in collaboration with FAO Regional Offices (FAO 2021c).

The GPNM provides support for the development and sharing of knowledge and the expansion of global and regional partnerships, particularly through the existing regional-level Nutrient Management Platforms and through planned regional GPNM platforms (UNEP 2021b). The INI is a scientific body established to review current understanding of the nitrogen cycle and identify options for optimizing the management of reactive nitrogen globally while minimizing its negative effects on human health and the environment (INI [International Nitrogen Initiative] 2021). The enforcement of certain WTO agreements can also contribute to reducing the amounts of fertilizers used (WTO 2021) (see Chapters 8.2-8.4).

### National policies and legislation on fertilizers

In general, the purpose of fertilizer legislation is to ensure that farmers are able to apply good quality fertilizers and that environmental damage resulting from fertilizer use is minimized. Fertilizers can be regulated through specific fertilizer and other types of legislation. Fiscal policies may be used to encourage or discourage fertilizer use.

The objectives of fertilizer regulations include provision of food and feed and the protection of the air, soil, aquatic ecosystems and people. The types of legislation and regulations related to fertilizer production, trade, distribution, marketing, safety and use can vary among or within countries based on their priorities with respect to fertilizer use and risks. Consequently, countries may use different combinations of instruments to achieve specific goals (FAO 2019a).

Regulation of the manufacture, trade and use of fertilizers can be related to various sectors and policies. National fertilizer legislation may cover all fertilizers or just formulated products. It may address only the production and/or use of fertilizers, or provide rules applicable to all stages of their life cycle. Some countries have developed legislation that establishes a registration mechanism for formulated fertilizers that mirrors the classical pesticide regulatory framework; others place greater emphasis on the risks associated with certain substances used in fertilizers, such as ammonium nitrate.

Fertilizers can be directly regulated by specific fertilizer legislation (addressing, for example, the registration/authorization of fertilizers on the market and their quality, or fertilizer labelling and packaging). They may also be covered by general legislation on agrochemicals or agricultural inputs. Other laws which can influence the regulatory framework for fertilizers and introduce specific rules or restrictions include:

- ▶ health or occupational safety legislation that addresses, for example, risks arising from the application and use of fertilizers;
- ▶ food safety and quality legislation including, for example, standards for potentially toxic trace elements, as well as biofortification legislation that includes, for example, guidance on agronomic biofortification;
- ▶ food security legislation that provides an enabling environment for fertilizer use;
- ▶ environmental protection legislation that restricts or regulates the use of certain substances including those in fertilizers (this legislation may cover, for example, air, soil, water or biodiversity);
- ▶ water legislation, for example on safe drinking water and the protection of surface and groundwater;
- ▶ climate change related legislation, for example on reducing agricultural emissions and combating desertification;
- ▶ soil legislation including, for example, guidance on soil fertility management;
- ▶ legislation that addresses the disposal of fertilizer waste, and sewage legislation covering treatment and disposal;
- ▶ fisheries and aquaculture legislation to protect aquatic species;
- ▶ livestock management legislation addressing animal production practices and manure management;

- ▶ explosives legislation that covers, for example, materials not intended for use as explosives but which have the potential to explode.

(See Chapter 8.5)

### Corporate responsibility and stewardship

The fertilizer industry is contributing to sustainable nutrient management. For example, it has developed the 4R Nutrient Stewardship guidelines (Johnson and Bruulsema 2014; 4R Nutrient Stewardship 2020) and helped to establish the Scientific Panel on Responsible Plant Nutrition (Scientific Panel on Responsible Plant Nutrition 2021). Fertilizers Europe is an association made up of 17 fertilizer manufacturers from countries across the European Union and eight national fertilizer associations. Its product stewardship programme “ensures the highest standard of

fertilizer safety and environmental performance from production to application”, including product development, sourcing of raw materials, additives and third party products, manufacturing, packaging, transportation, storage, marketing and sales, product application and farmer services (Fertilizers Europe 2022).

The Sustainability Consortium (TSC) is a global non-profit initiative consisting of manufacturers, retailers, suppliers, service providers, non-governmental organizations (NGOs), civil society organizations, government agencies and academics. The TSC works collaboratively to build science-based decision tools and solutions and transform the consumer goods industry by partnering with leading companies in order to define, develop and deliver more sustainable products (TSC [The Sustainability Consortium] 2022) (see Chapter 8.6).

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# Adverse environmental and health effects of pesticides and fertilizers

## 3.1 Pesticides

Pesticides are by definition biologically active compounds. They are among the few types of chemicals that are purposely administered in the environment rather than being a by-product of other processes. Their use can pose risks to humans and other non-target organisms.

Using pesticides will virtually always pose certain risks. The likelihood and importance of these risks may depend on, for example, the dose, the use situation, the exposed organisms or ecosystems, and the timing of exposure. Nevertheless, pesticides are widely used because their risks have been judged to be acceptable, although often on the condition that specific risk mitigation measures are applied. Pesticide toxicity, or potential environmental and health risks, have been reviewed in detail (Brock *et al.* 2010; Krieger 2010; National Research Council 2013; Roberts and Reigart 2013).

Furthermore, extensive regulatory hazard and risk assessments of individual pesticides have been published by international entities such as the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) (FAO 2021d) and the International Agency for Research on Cancer (IARC 2021), as well as by national or regional regulatory authorities such as the European Food Safety Authority (EFSA 2021), the United States Environmental Protection Agency (US EPA 2021) and the Australian

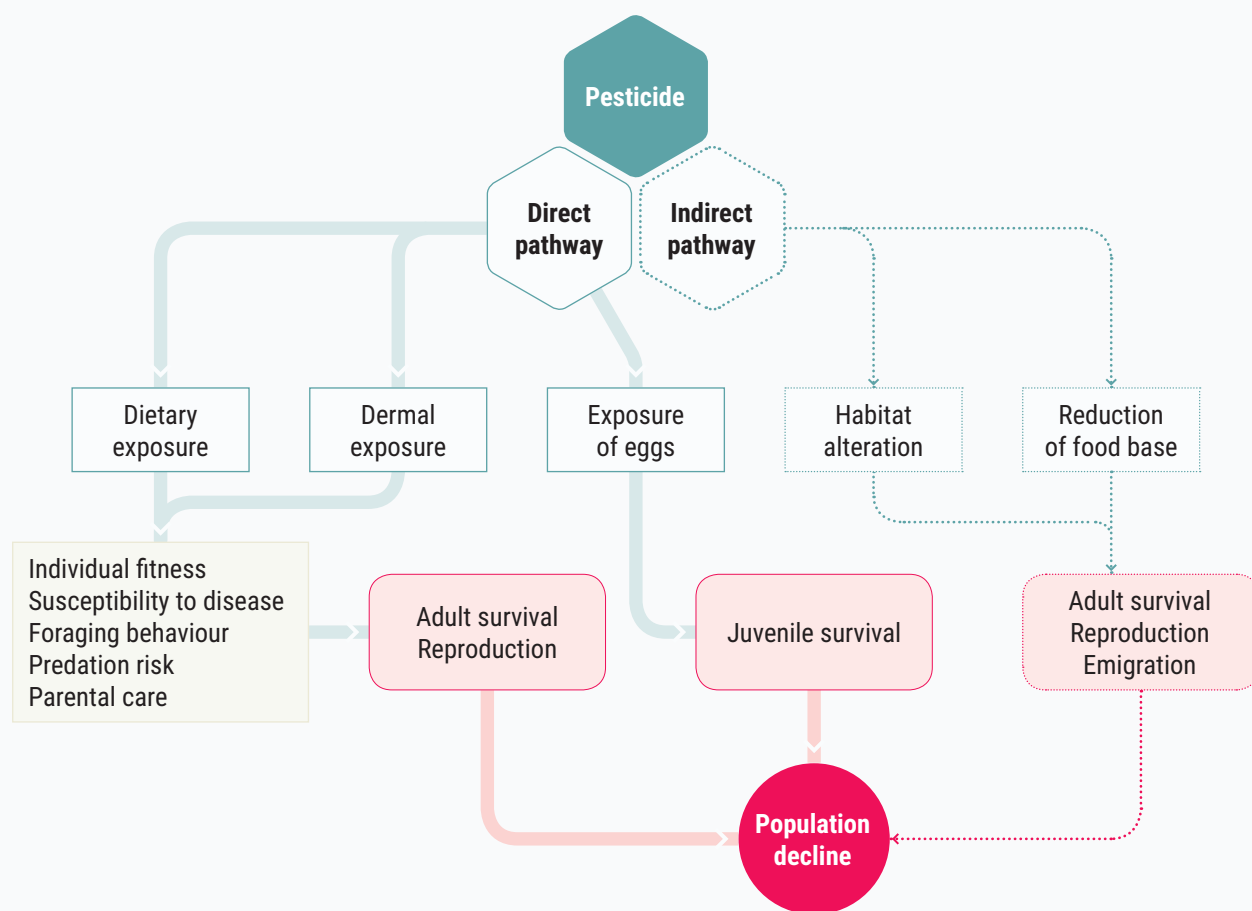
Pesticides and Veterinary Medicines Authority (APVMA 2021), among others (see Chapter 4).

### Adverse environmental effects of pesticide use

Pesticides are applied in the environment on purpose. They therefore, almost by definition, pose risks to non-target organisms. Depending on pesticide use patterns, the toxicity of the pesticide, the conditions of exposure of non-target organisms and the type of agro-ecosystem exposed, environmental risks will range from very high to virtually absent.

Pesticide residues are increasingly monitored in the environment on a more or less regular basis. They have been detected in a wide range of environmental media, including surface and groundwater, soils and air. Trends in their atmospheric concentrations have not been systematically reviewed and are less well documented than concentrations in other environmental compartments. Nevertheless, legacy organochlorine pesticides are detected in the air almost everywhere (Kirchner *et al.* 2016; Wang *et al.* 2019). Wherever pesticides have been measured in surface waters they have been found to be ubiquitous, in many cases exceeding national surface water standards and not always showing downward trends over time either for legacy organochlorine pesticides or current use pesticides (Stehle and Schulz 2015;

► **Figure 9 Pathways through which pesticide application can ultimately lead to population declines in terrestrial vertebrates.** (based on Amaral *et al.* 2012a; Stanton, Morrissey and Clark 2018).



Stehle, Bub and Schulz 2018). Data on pesticide concentrations in groundwater and drinking water are generally scarce for many parts of the world and for many pesticides. Pesticide residues appear to be omnipresent in agricultural soil. They are also detected in non-treated areas and soils of organic production systems (Silva *et al.* 2019; Pelosi *et al.* 2021).

The use of pesticides has been associated with adverse impacts on populations of non-target organisms. Direct effects of (mainly) insecticides have been linked to population reductions of terrestrial insects and aquatic arthropods (Sánchez-Bayo and Wyckhuys 2019; Sattler *et al.* 2020). Pesticide use may affect ecosystem services, particularly pollination, soil function, pest regulation, food production and maintenance of future options. In some countries the direct effects can ultimately lead to population declines

in terrestrial vertebrates (Figure 9). Despite limitations in research, it can be concluded that whenever large-scale studies or reviews are available the majority show that pesticide use has adverse effects on biodiversity (see Table 4.3.6-1 in Chapter 4.3.6).

A number of adverse environmental effects of pesticide use can have direct or indirect impacts on the sustainability of agricultural production or of disease vector control. They include:

- Development of resistance against pesticides in pest organisms or disease vectors

The development of resistance against pesticides in arthropods, weeds, rodents and other disease vectors is an important agronomic, economic, ecological and public health problem throughout the world. It is

characterized by the repeated failure of a pesticide to achieve the expected level of control when used according to the label recommendation for that pest species. By late 2019 almost 17,000 cases of arthropod resistance to 345 different pesticides had been reported globally, representing more than 600 species of insects and mites (Mota-Sanchez and Wise 2019). Of these, almost 95 per cent of cases of resistance in 587 species were field-evolved: that is, they were the result of pesticide use under actual field conditions rather than in the laboratory. Development of pesticide resistance not only affects ecosystems but can have adverse impacts on human health.

- ▶ Impacts on bees and other pollinators and possible reduction of crop pollination

Pollinators can be found in different groups of animals, but are dominated by insects, mainly bees. By far the most information about the adverse effects of pesticides on pollinators addresses honeybees. Acute mortality of honeybees appears to be declining in countries with effective regulation or enforcement of mitigation measures (Kovács-Hostyánszki *et al.* 2016). Adverse pesticide effects on other pollinators (e.g. flies, butterflies or bats) are limited.

- ▶ Impacts on natural enemies of pests, and possible pest resurgence or appearance of secondary pests

Natural enemies of crop pests or disease vectors often keep pest populations below levels that cause crop losses. A pesticide treatment may control the pest population, but it can also kill, repel, irritate or otherwise deter the natural enemies of that pest. This can sometimes lead to pest resurgence or secondary pest development (Cloyd 2012; Roubos, Rodriguez-Saona and Isaacs 2014). However, as no recent systematic review has been published on this topic, it is unclear whether resurgence and secondary pest development are less frequent today than in the past.

- ▶ Effects on soil organisms and possible reduction of soil fertility

Soil organisms provide essential contributions to many soil functions, including nutrient cycling, soil formation, regulation of pests and diseases, and food, fibre and water supply. Pesticide applications in the field have led to variable effects on soil microbial communities and activity. Despite the importance of soil quality for agricultural (and natural) production, relatively little monitoring and few large-scale field studies have been conducted to assess the impact of current pesticide use on soil organisms and processes.

(See Chapter 4.3)

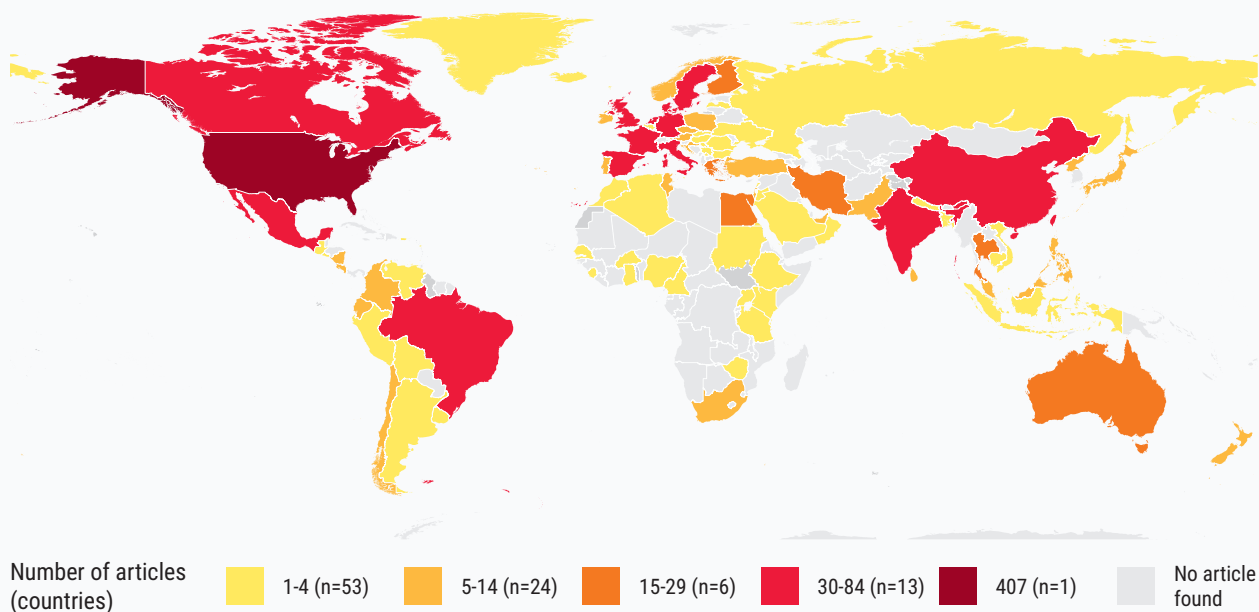
### Adverse health effects of pesticide use

Almost all humans will be exposed in some way to pesticides through working with these products or living near agricultural fields, through diet, through products containing pesticides (e.g. impregnated mosquito nets or clothing, house paints) or via the environment.

Exposure to pesticides can be acute or chronic. Examples of acute exposure include accidents, occupational exposure and self-poisoning, which tend to involve relatively high levels of exposure to pesticides. Chronic exposure occurs through, for example, diet, working for longer periods with pesticides, and exposure to pesticides in the local environment. Levels of exposure may depend on several factors, including seasonality, occupation, behaviour at work/home, age and gender (Roberts and Reigart 2013; WHO 2020).

Numerous epidemiological studies have been conducted with the aim of assessing associations between exposure to pesticides and health outcomes such as the development of specific diseases. However, the majority of studies on occupational exposure to pesticides (83 per cent) originate in high- and upper-middle-income countries and very few (1.1 per cent) are from low-income countries (Ohlander *et al.* 2020) (Figure 10). It is very difficult to prove that a pesticide has caused an adverse health effect based on epidemiological

► **Figure 10** Number of articles published on occupational exposure to pesticides and various health outcomes between 1993 to 2017, per country serving as a study location. Ohlander *et al.* (2020)



Note: Numbers in brackets refer to the number of different study locations (countries)

studies alone. More evidence is often needed to infer such causality. Based on reviews and meta-analyses, however, positive associations between pesticides and certain health outcomes have been reported (Prüss-Ustün *et al.* 2016; Ntzani *et al.* 2020).

Based on the epidemiological evidence, chronic adverse health effects are considered likely as a result of exposure to pesticides in general or to certain groups of pesticides. In only a few cases were associations between specific pesticides and a health outcomes characterized and quantified. This difficulty is inherent in regard to identifying specific exposures in epidemiological studies. However, such limitations do not necessarily preclude taking risk reduction measures before risk characterization becomes more precise (Ntzani *et al.* 2020) (see Chapter 4.4).

Reviews suggest that unintentional acute pesticide poisoning is widespread and that it has increased since earlier estimates dating from the 1990s. However, data on acute poisoning from different sources are variable and incomplete. There is a need for standardized surveys of pesticide exposure and pesticide poisoning, including

collection of information from poison centres. According to a major systematic review covering the period 2006-2018, about 385 million cases of unintentional acute pesticide poisoning and approximately 11,000 fatalities occurred annually (Boedeker *et al.* 2020). Furthermore, it has been estimated that 1 to 2 million cases of self-poisoning occurred annually between 2006 and 2015, resulting in about 168,000 deaths (Mew *et al.* 2018). Self-poisoning occurs primarily in rural areas of low- and middle-income countries in Africa, Asia and Central America.

There is also evidence of significant associations between occupational or residential exposure to specific groups of pesticides (or to pesticides in general) and various adverse health outcomes including cancers and neurological, immunological and reproductive effects. Exposure to pesticides during pregnancy and/or childhood has been associated with pregnancy loss and leukemia in children (Ntzani *et al.* 2020). On the other hand, most of the information currently available on pesticide residues in food appears to indicate that pesticide dietary risks are low (see table 4.4-13 in Chapter 4).



A limited number of pesticides appear to be responsible for a disproportionate share of adverse health impacts, resulting in a focus on addressing Highly Hazardous Pesticides (HHPs) in pesticide risk reduction measures (FAO and WHO 2016).

There are many examples of adverse impacts being reduced through actions addressing pesticides. For example, in countries with strict regulations concentrations of organochlorine pesticides in the environment are decreasing and acute environmental and health effects caused by highly toxic organophosphate and carbamate pesticides have fallen (Mineau and Whiteside 2006; Tassin de Montaigu and Goulson 2020).

Despite the risk assessment and management procedures in place, adverse environmental and health impacts occur even in the case of authorized uses. This is true despite ongoing significant investments in risk reduction measures such as training and the use of personal protective equipment (PPE). Reviews of the effectiveness of training in and use of PPE show that this equipment is only partially effective in reducing exposures and adverse effects (Garrigou *et al.* 2020; Sapbamrer and Thammachai 2020).

### Knowledge gaps: environmental and health effects of pesticides use

Many knowledge gaps have been identified in regard to the impacts of pesticide use on the environment. Very few systematic reviews have been conducted of the available data, or of what the implications of these data might be for pesticide risks and their mitigation options. Despite advances in strengthening environmental risk assessment procedures, unexpected environmental impacts are frequently identified – typically many years after a pesticide was placed on the market (Boyd 2018; Group of Chief Scientific Advisors 2018; Brühl and Zaller 2019; Schäfer *et al.* 2019; Topping, Aldrich and Berny 2020).

Systematic monitoring of pesticide concentrations in environmental compartments such as air, surface water, groundwater and soil is only conducted in some parts of the world; large data gaps exist in many others. Systematic monitoring of adverse effects on non-target organisms

or communities is virtually absent in low- and middle-income countries and is rare even in high-income economies. Owing to the limitations of current prospective risk assessment procedures and the lack of systematic post-registration monitoring, significant gaps in knowledge about adverse effects of current pesticide use on the environment persist. Recently, explicit calls for broader and more intensive post-registration monitoring or vigilance of pesticide use, concentrations and effects have therefore been made (Milner and Boyd 2017; Rico *et al.* 2020; Topping, Aldrich and Berny 2020).

Many recommendations have been made on how best to strengthen environmental risk assessment through the generation of additional pesticide toxicity or fate data, the development of new or better risk assessment models, or even the introduction of new risk assessment paradigms. Strengthening post-registration environmental monitoring of pesticide concentrations and effects should therefore have the highest priority.

Concerning the human health effects of pesticides, much knowledge has been amassed during the last few decades indicating that there is scope for further improvement of the scientific data that underpin pesticide risk assessments as well as the methods used to analyze such data. Knowledge gaps have also been identified in regard to the priorities for research on the health effects of pesticides, toxicological testing, and risk assessment approaches. Based on the reviews carried out, the following gaps in scientific knowledge, which are important with respect to reducing the future impacts and health risks of pesticide use, can be identified:

- ▶ toxicological evaluations of more complex human health outcomes such as immunotoxicity, childhood leukemias, developmental neurotoxicity, chronic neurological diseases such as Parkinson's disease, neuropsychological effects and mental illnesses, as well as endocrine disorders such as some hormonal cancers, endometriosis, metabolic syndrome, type-2 diabetes, and reproductive senescence;

- ▶ toxicological assessments of co-formulants and of formulated products;
  - ▶ assessments of detailed mechanisms by which chemicals interact with the body, and the adverse outcome pathways (AOPs) through which they might cause harm;
  - ▶ new toxicological methods that reduce the use of animals in testing, including the application of in vitro toxicogenomics;
  - ▶ the risk of combined effects from exposure to multiple active substances, either simultaneously or in sequence;
  - ▶ further development and standardization of methods for cumulative dietary risk assessments;
  - ▶ ascertain that prevailing human health risk assessments are sufficiently protective for potentially sensitive populations such as immuno-depressed persons, female farmers and agricultural workers, pregnant and nursing women, and children;
  - ▶ levels and determinants of exposure, especially of pesticide applicators using handheld or backpack sprayers, and of workers who enter crops that have been treated with pesticides;
  - ▶ better characterization and quantification of exposure to pesticides in epidemiological studies;
  - ▶ “real life” behaviours of pesticide operators in regard to the use of equipment and application techniques, and the extent to which such approaches can be used to manage or reduce exposures;
  - ▶ standardized risk assessment procedures for nanopesticides and for biopesticides;
  - ▶ the impact of pesticide use on the development of antimicrobial resistance;
  - ▶ consideration of the rapidly growing body of epidemiological evidence, especially when reviewing approvals for products already on the market;
  - ▶ post-marketing surveillance of approved pesticides (e.g. through establishing or strengthening poison centres) to verify that they do not cause unanticipated human health problems.
- (See Chapters 4.3.7 and 4.4.8)

## 3.2 Fertilizers

### Adverse environmental effects of fertilizer use

Air pollution related to fertilizers includes the contribution of their use to anthropogenic greenhouse gas emissions, ammonia emissions and particulate matter (PM<sub>2.5</sub>). Ammonia, the main PM<sub>2.5</sub> precursor from agricultural activities (Bauer, Tsigaridis and Miller 2016; Wu *et al.* 2016), is emitted from heavily fertilized fields and livestock waste. The ammonia released combines with other precursors (mainly nitrogen oxides and sulphates) to form particulate matter.

Contaminants from fertilizers in the terrestrial and aquatic environments include nutrients (e.g. from excessive application of fertilizers), metals (e.g. cadmium), endocrine disrupters and antibiotics (Rodríguez Eugenio, McLaughlin and Pennock 2018).

The terrestrial and aquatic contaminants of which fertilizers are a source can affect soil quality and microorganisms, invertebrates and other animals directly or, for example, through the food chain.

Contaminants in fertilizers (e.g. trace elements and pathogens in biosolids) can pollute soils and water bodies. Excess nutrients from applied fertilizers may also be transported to nearby water bodies (e.g. streams and lakes) by means of rainwater, erosion, tile drains and other drainage systems, irrigation channels and seepage, and on to underground water supplies through leaching.

### Box 1 General findings of two epidemiological reviews on fertilizers carried out for this report: fertilizers and human health, and cadmium case study\*

The first of two reviews carried out for this report was a systematic review of epidemiological studies linking fertilizer use and human health effects. Few studies were identified for final inclusion (47 for inorganic fertilizers, 17 for organic ones). The outcomes with the largest number of studies were cancers for inorganic fertilizers and infections for organic ones. The studies reported significant, not significant or inconclusive findings for the outcomes studied. Although the epidemiological review highlighted several limitations of the studies (e.g. study design, poor exposure assessment), it concluded that this is an emerging evidence base.

The second was a review and appraisal of published systematic reviews and/or meta-analyses on potential associations of cadmium exposure with human health-related outcomes. Among the assessed publications, the outcomes studied included kidney disease, cancers, endocrine disorders and cardiovascular disease. Significant, not significant or inconclusive findings were reported. Fertilizers were mentioned in some publications, but no study assessed fertilizer use as a source of cadmium exposure.

The findings of the two reviews are a clear indication of the existing data gap with regard to the health effects of fertilizers.

\*The full reviews are presented as an annex to the comprehensive compilation of scientific information.

In the aquatic environment excess nutrients (primarily nitrogen and phosphorus) contribute to eutrophication (which can lead to hypoxia) (Khan *et al.* 2018). and damage coral reefs (American Geophysical Union 2020). They can adversely affect algae, fish and other aquatic life. Hence, excess nutrients in the environment affect the food web at all levels (e.g. primary, secondary and tertiary consumers) (World Resources Institute 2013) (see Chapter 9.2).

#### Adverse health effects of fertilizer use

Fertilizers have been identified as among the sources of contamination and pollution of air, water and soil. Thus they can potentially affect human health (de Paz *et al.* 2009; Ward *et al.* 2018; Yu *et al.* 2020). For example, nitrates in drinking water are associated with negative health effects although fertilizers are not their only source (Mateo-Sagasta, Zadeh and Turrall 2018). However, few studies suggest that fertilizers have adverse effects on human health. In real life the pathways connecting fertilizer contaminants/emissions to human health effects are not distinct and can be rather complex.

As in the case of pesticides, knowledge gaps regarding the adverse health effects of fertilizer use have been identified (Box 1).

#### Adverse effects of occupational exposure

The reported adverse effects of occupational exposure to fertilizers mainly concern contact or inhalation of ammonia from fertilizers and manure. Short-term inhalation exposure to high levels of ammonia in humans can cause irritation and serious burns in the mouth, lungs and eyes (US EPA 2016). Chronic exposure to airborne ammonia can increase the risk of respiratory irritation, cough, wheezing, tightness in the chest, and impaired lung function in humans (US EPA 2016).

Explosions and fires in storage settings involving nitrogen fertilizers with high levels of reactivity, are another hazard associated with fertilizers (US EPA 2015; Laboureur *et al.* 2016; Guglielmi 2020; EC n.d).

#### Adverse effects of dietary exposure

Adverse effects of dietary exposure can occur in the case of trace elements, particularly cadmium; nitrates (Rodríguez Eugenio, McLaughlin and Pennock 2018); and urea and pathogens in organic fertilizers. Potentially toxic trace elements can be ingested through food and water intake (Gall, Boyd and Rajakaruna 2015). The relationship between fertilizers and antimicrobial resistance, toxins in eutrophic water bodies, and the effects of

fertilizers on food quality are also areas of concern (see Chapter 9.3).

### **Interlinkages between the environmental and health effects of fertilizer use**

The environmental impacts of fertilizer use can have negative effects on human health and nutrition. For example, degradation of the terrestrial and aquatic environments affects the sustainability of food production, and therefore human health and food security.

Changes in insect vector populations due to fertilizer use can affect the spread of communicable diseases. It has been hypothesized that increasing nutrient availability could often favour disease-causing organisms (Townsend *et al.* 2003). Although studies linking fertilizers to diseases transmitted by such vectors appear to be lacking, the fact that studies have demonstrated a positive relationship between fertilizer use and vectors indicates that its use can increase incidences of some vector-borne diseases in humans.

Studies have also suggested that changes in human diet can affect both the environment and human health (Marlow *et al.* 2009; Sabaté and Soret 2014). The theory that increased adoption of plant-based diets has positive effects on the food supply is based on the premise that increased intake of more plant-based foods together with reduced intake of animal-based foods is likely to reduce the amounts of fertilizers used (see Chapter 9.4).

### **Knowledge gaps: environmental and health effects of fertilizer use**

While there are indications that fertilizers can have adverse effects on the environment and health, some of the potential impacts of these effects may be unknown. According to the review carried out for the report, for example, there were few studies linking fertilizer use and health effects (Box 1 above). Some studies reported insignificant or inconclusive findings, and the studies had limitations (e.g. in regard to study design, poor exposure assessment).

Lack of adequate data on adverse effects for use in decision-making has been highlighted (Rodríguez Eugenio, McLaughlin and Pennock 2018). In the case of fertilizers, risk assessment is constrained by, for example, large gaps in available information on health effects as well as in toxicological data. Estimating the risks posed by contaminants and pollutants from diffuse sources is difficult. Moreover, the contribution of fertilizers to adverse environmental and health effects is challenging to estimate as fertilizers are not the only source of these effects in the environment. A shift may be needed in the focus of research towards analysing multiple, contemporaneous types of risks, including risks related to the environmental and health effects of overuse or inappropriate handling of inorganic fertilizer (see Chapter 9.5).

# Social and economic impacts of pesticides and fertilizers

## 4.1 Pesticides

Pesticides are sold and used because of the benefits they are expected to provide. The potential benefits of pest control (of which pesticides are an instrument) include reduced crop losses, reduced prevalence of human vector-borne diseases, longer shelf life of agricultural commodities, greater livestock yields, reduced soil disturbance, and better protection of wooden structures.

No recent independent global or regional reviews of the economic benefits of pesticide use are available. While the pesticide industry certainly collects information about the costs and benefits of their products internally, such data do not seem to be publicly available for systematic review and independent analysis.

- ▶ Pesticide use has different types of costs: direct costs, which are all the monetary and non-monetary expenses borne by farmers and other pesticide users; indirect or hidden costs (e.g. occupational health effects, development of pest resistance, or reduction in crop pollination); and external costs or externalities, which are the costs of pesticide use borne by society as a whole (e.g. pesticide regulation, treatment of polluted water, clean-up of stocks of obsolete pesticides).

Despite great uncertainties associated with estimates of the indirect environmental and health costs of pesticide use, these costs are

likely to be high. The most recent review of annual indirect environmental and health costs found that they ranged from USD 5.5 million in Niger in 1996 to USD 12 billion in the United States in 2005 (Bourget and Guillemaud 2016). More recent estimates of the health costs of endocrine disrupting pesticides amount to tens of billions of US dollars in both Europe and the United States (Trasande *et al.* 2015; Attina *et al.* 2016; Trasande *et al.* 2016).

- ▶ Very few comprehensive assessments are available comparing the overall costs of pesticide use with their estimated benefits. If indirect costs are not taken into account, benefit-cost ratios at farm level tend to average between 3 and 6 (i.e. USD 1 spent on pesticides and their application yields USD 3-6 in benefits to the farmer) (see Table 5.3-4 in Chapter 5.3); if hidden private costs and externalities are included, benefit-cost ratios are much reduced and in some cases are below 1. Most indirect costs are borne by society as a whole. These indirect costs are generally not taken into account in decision-making about pest control at either the private or government level (see Table 5.3-5 in Chapter 5.3).
- ▶ The overall adverse human health impact of pesticides can be quantified as burden of disease. So far, no international estimates are available of the burden of disease caused by pesticides with the exception of self-poisoning.

- ▶ Pesticide use may affect ecosystem services, in particular pollination, soil function, pest regulation, food production and maintenance of future options. There is clear longstanding evidence that pesticides adversely affect the natural regulation of pests and other detrimental organisms (Millennium Ecosystem Assessment 2005). High levels of pesticide use also impact pollination, although it is less clear whether sublethal exposure of pollinators leads to a reduction in pollination services (Kovács-Hostyánszki *et al.* 2016). The circumstances under which pesticide use affects soil functions are currently unclear and require further research. Food and feed production can be positively or negatively influenced by pesticides, depending on the circumstances of their use.
- ▶ Relatively few studies have been conducted on pesticides' impact on biodiversity and the associated capacity of (agro-)ecosystems to adapt to change. Where such studies have been carried out, biodiversity was generally shown to be adversely affected by pesticide use.

Large gaps still exist in our understanding of pesticides' ultimate environmental, health and economic impact under current conditions of use. Thus, informed decision-making about the best and most sustainable forms of pest and vector management, and the role of pesticides therein, is handicapped by lack of the comprehensive knowledge needed to develop sound national and regional policies (see Chapters 5.1, 5.2, 5.3 and 5.4).

## 4.2 Fertilizers

### Environmental and health costs

Pollution is a serious problem globally, fertilizers contribute to pollution, and the planetary boundary for nitrogen and phosphorus flows is considered to have been crossed (Stockholm Resilience Centre 2021). At the same time, global demand for nourishing food will continue to grow. Despite indications that fertilizers can have adverse impacts on the environment and health, there are



no global studies on the total costs of fertilizer pollution. Estimates indicate that both the total benefits and total costs of nitrogen use could be very large (van Grinsven *et al.* 2013; Sobota *et al.* 2015; IPBES 2019, although there is much uncertainty about the data as well as considerable data gaps. There is clearly a need to increase efforts aimed at sustainable nutrient management.

There are no estimates of global premature deaths due to fertilizers. It has been estimated that a 50 per cent reduction in agricultural emissions could reduce the number of premature deaths by 250,000 per year; assuming there were no agricultural emissions, premature deaths would be reduced by 800,000 (Pozzer *et al.* 2017). It should be noted that on this topic no other publications with global coverage were found.

No global estimates exist of the total human health costs of fertilizer use. However, estimates have been made of the costs of pollution by nitrogen and other pollutants, pathogens, and antimicrobial resistance (AMR), to all of which fertilizers are a contributor.

Several studies have estimated the damage costs of agricultural nitrogen to human health. Global damage to the coastal aquatic environment by nitrogen and phosphorus, associated with hypoxia, was estimated by Sutton *et al.* (2019) to be about USD 170 billion annually. These costs vary among regions. Studies have estimated the costs of eutrophication in the European Union and the United States to be in the billions of dollars.

In the case of pathogens, the monetary value of health costs could be at least USD 1 billion annually. For example, health costs related to foodborne pathogens have been estimated to be about USD 380 million/year. A study of AMR-related health costs in Organisation for Economic Co-operation and Development (OECD) and European Union/European Economic Area (EEA) countries found that improved use of antibiotics could reduce deaths from AMR by half and save about 2.3 billion euros (Anderson *et al.* 2019). The contribution of manure to AMR was not estimated. Since about 70-80 per cent of antibiotics produced are used in livestock, it is possible that a proportion of these costs is due to handling and use of manure. However, according

to a study by Miller *et al.* (2019), transmission of AMR to food grown in soil to which animal manure has been applied may be minimal.

Little is known about the costs of nutrient losses in regard to ecosystem services such as water regulation and biodiversity. For example, no data were found concerning the impacts of nutrient loads on water regulation services provided by wetlands, although wetlands provide services such as water supply and the control of pollution and flooding. Loss of coastal habitats and coral reefs increases risks from floods and hurricanes to life and property for an estimated 100-300 million people (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production 2019) (see Chapter 10.2).

### **Agronomic, economic, health and environmental benefits**

Historically, the use of fertilizers, in combination with improved varieties and better management practices, has resulted in increased yields and production. For example, cotton yields tripled in West Africa between 1960 and 1985 with increased fertilizer use and better management practices.

Globally, over 2 billion people are estimated to suffer from micronutrient deficiencies caused by dietary deficiencies of nutrients and vitamins. The estimate by Peng and Berry (2018) that 33-50 per cent of the world population is micronutrient deficient is consistent with the 2 billion people estimated in *The State of Food Security and Nutrition in the World 2020* (FAO *et al.* 2020). In 2019 at least 340 million children under five were estimated to suffer from micronutrient deficiencies (United Nations Children's Fund 2019). Case studies on the health benefits of consuming foods biofortified through fertilizer use are scarce, but the benefits of addressing malnutrition can outweigh the costs. It has been estimated that addressing global micronutrient deficiency through supplementation, food biofortification and agronomic biofortification would incur estimated annual costs of about USD 1.2 billion with benefits of about USD 15.3 billion (Global Panel on Agriculture and Food Systems for Nutrition 2016).

Global data on the economic benefits of fertilizer use are lacking and the available data do not allow such an overview. Global studies comparing the economic benefits of using fertilizers (for farmers) with damage costs are also lacking. Existing studies suggest that the cost of pollution could either outweigh or be outweighed by the economic benefits of fertilizer use. For example, estimates by van Grinsven *et al.* (2013) suggest that the cost of pollution from nitrogen use in agricultural production in the EU-27 in 2008 could have been greater than the economic benefit (35-230 billion euros/year vs. 20-80 billion euros/year). In China Tang *et al.* (2019) reported that an increase in the net economic value of vegetables due to use of fertilizers (inorganic and organic) outweighed environmental and health costs (i.e. damage to ecosystems and human health and contribution to global warming) by  $\geq 15$  times.

Although experiments and meta-analysis of published experimental data have reported that fertilizers can have positive effects on soil carbon, literature concerning the quantification of the impacts of fertilizer on soil carbon is scarce (see Chapter 10.3).

## Data gaps and challenges

There are large data gaps with respect to the impacts of fertilizer use, and assessments of the global social costs of nutrient pollution are subject to many uncertainties (Sutton *et al.* 2013). Moreover, the existing data are not disaggregated by gender, age or fertilizer type (i.e. organic compared to inorganic fertilizers).

There are also large data gaps concerning the environmental effects of fertilizer use and on the impacts of fertilizers on human health. While a key objective of governments is to improve people's health and welfare, their investment priorities may not include monitoring fertilizers' adverse impacts.

Where data exist, it is difficult to compare the values of pollution costs from different studies. Various assumptions are made, for example in monetizing the different species of reactive nitrogen. Moreover, it is difficult to predict or estimate damage costs as these costs are influenced by, for example, fertilizer type, management practices and ecosystem characteristics (see Chapter 10.4).





# Options for minimizing the adverse impacts of pesticides and fertilizers

The sound management of chemicals, including hazardous waste, aims to prevent and – where that is not feasible – reduce or minimize the potential for exposure of the environment and people to hazardous chemicals. Sound management includes the prevention, reduction, remediation, minimization and elimination of risks during the life cycle of chemicals (production, storage, transport, use and disposal) and of risks posed by chemicals in products and articles (UNEP 2019).

## 5.1 Pesticides

### Assessment of current pesticide risk reduction measures

Some risk reduction measures which have already been taken are briefly described below, although adjustments to these measures may be required in order to further minimize the adverse environmental and health impacts of pesticides (see Chapter 6.2).

#### Regulatory measures

Several international Conventions address pesticides directly or indirectly. One of the main constraints of many of these Conventions is that their success largely depends on national capacities to implement their provisions and on levels of commitment to do so (see Chapter 6.2.1).

Tables 1-4 summarize the strengths, limitations, opportunities and challenges of:

- ▶ regulatory and policy measures used to reduce the environmental and health risks of pesticides (Table 1);
- ▶ economic measures used to reduce the environmental and health risks of pesticides (Table 2);
- ▶ training and awareness building used to reduce the environmental and health risks of pesticides (Table 3);
- ▶ engineering controls and technologies that can be used to reduce the environmental and health risks of pesticides (Table 4).

#### Market-based measures

Market-based measures that can be used to reduce the environmental and health risks of pesticides include subsidies, taxes, private standards, and the internalization of externalities. This report mainly focuses on subsidies and taxes (see Chapter 6.2.2).

#### Training and awareness building

Awareness about the threat pesticide use poses to the environment and human health, and the ways such risks can be minimized, is a prerequisite for changing policy and behaviours towards more

**Table 1 Regulatory and policy measures used to reduce the environmental and health risks of pesticides: strengths, limitations, opportunities and challenges**

Measure	Strengths	Limitations	Opportunities	Challenges
International Conventions Chapter 3.2	Address transboundary pesticide risks and set international standards. Promote strengthening of national legislation Most countries are Parties to these Conventions.	The objectives and obligations of respective international Conventions are by definition limited in scope. Pesticide issues may exist that are outside the scope of current Conventions.	International frameworks are in place which can, in principle, be strengthened. Global coordination, communication and information sharing are in place.	Contribution to risk reduction largely depends on national priorities and capacity for implementation. Addressing risk reduction measures outside the scope of respective Conventions is limited and not obligatory.
Regional instruments and mechanisms Chapter 3.3	Assembling countries that face similar situations facilitates mutual understanding and collaboration.	Effectiveness of regional activities is still highly dependent on national implementation.	Regional collaboration mechanisms may increasingly be established.	Mobilization of funding for regional structures and activities.
Highly Hazardous Pesticides (HHPs) risk reduction Chapter 3.2	Potentially high impact for limited investments.	Addresses a limited number of pesticides; others may also pose high risks.	Global Action Plan for HHPs risk reduction developed under the Strategic Approach to International Chemicals Management (SAICM).	Creating a sense of urgency on the part of policymakers Identifying cost-effective alternatives.
National pesticide legislation Chapter 3.4	Provides a legal basis to implement sound pesticide management.	Public health and other non-agricultural pesticides are often inadequately covered. Implementation and enforcement are weak in many countries.	Most countries have some form of pesticide legislation in place. Successes exist with national bans on HHPs for the purpose of suicide prevention.	Effective implementation of legislation requires political awareness and support.
Pest and pesticide management policy Chapter 3.4	Clarifies pest management and pesticide use goals and targets for all stakeholders.	Very few countries have established dedicated, stand-alone national policies.	Lessons can be learned from countries that have experience with such policies,	Formulating policies that are applicable within broader national priorities and development plans. Converting adopted policy into concrete actions.
Control and enforcement Chapter 3.4	One of the main tools to ensure effectiveness of legislation.	Even if legislation is in place, control and enforcement are often inadequate. Coordination among responsible government entities is often inadequate.	Lessons can be learned from countries with effective control and enforcement systems.	Establishing or strengthening effective enforcement systems with only limited human and financial resources.

Measure	Strengths	Limitations	Opportunities	Challenges
Pesticide evaluation and registration Chapter 3.4	Ensures that pesticides authorized for use are effective and do not pose unacceptable risks, based on the available knowledge.	Human and financial capacities for pesticide registration in low-income countries are very limited. Duplication of pesticide evaluations by different national regulatory authorities.	Pesticide regulatory evaluations increasingly publicly available. More regional collaboration for pesticide registration.	Optimizing the use of limited resources to conduct efficacy and risk evaluations of pesticides, both nationally and internationally.
Post-registration monitoring Chapter 4.3.7	Allows risk mitigation measures to be taken if adverse environmental, health, agronomic or economic effects are observed.	Post-registration monitoring of pesticide use and impact is almost absent in low- and middle-income countries.	Monitoring of pesticide sales or use is increasingly required. Experiences exist with low-cost, community-driven monitoring.	Integration of monitoring into the pesticide regulatory system. Development of cost-effective monitoring systems, especially in low- and middle-income countries.

**Table 2 Economic measures used to reduce the environmental and health risks of pesticides: strengths, limitations, opportunities and challenges**

Measure	Strengths	Limitations	Opportunities	Challenges
Pesticide subsidies (both direct and indirect)	Can promote the use of low-risk pesticides.	Can result in excessive general pesticide use (including high-risk products).	Countries are increasingly abandoning general direct and indirect subsidies for pesticides. Some countries have introduced targeted subsidies on low-risk or biological pesticides.	Ensuring that subsidies promote the use of low-risk pesticides.
Pesticide taxes	Differentiated taxes can shift the behaviours of producers and consumers towards use of low-risk pesticides. Even relatively low taxes can generate revenues for sound pest and pesticide management.	Demand for pesticides is relatively inelastic, and high taxes tend to be needed in order to reduce pesticide use. Taxes have been found ineffective if used in isolation from other policy measures.	Lessons can be learned from countries which have applied different forms of pesticide taxes.	Addressing concerns about producer competitiveness on the global market. Ensuring that tax revenues are used to support producers.
Private standards	Standards that require organic production or integrated pest management (IPM) may reduce the environmental and human health effects of pest management. A direct link is created between sound pest and pesticide management and the opportunity to sell produce.	The number and strictness of private standards may disfavour small-scale farmers with limited technical support.	Consumers and retailers, especially in middle- and high-income countries, are increasingly purchasing food produced with no or few pesticides.	Certain (elements of) private standards may not be based on sound science. Capacity needs to be built so that smallholder farmers can meet the standards. Extra investments required to be made by producers should be covered through a bonus on the price paid for commodities produced according to the standard.

Measure	Strengths	Limitations	Opportunities	Challenges
Internalization of indirect health and environmental costs	Creates a level playing field for pesticides with different environmental and human health risks.	Costs and benefits are not the only drivers of farmer behaviours regarding pesticide use.	Lessons learned from targeted and differentiated pesticide subsidies and taxes, while still limited, might be applied elsewhere.	The difficulty of calculating the value of externalities. Existing estimates are outdated.

**Table 3 Training and awareness building used to reduce the environmental and health risks of pesticides: strengths, limitations, opportunities and challenges**

Measure	Strengths	Limitations	Opportunities	Challenges
Awareness building about pesticide risks for policymakers, pesticide users and the public	Prerequisite for changing policy and behaviours. Awareness has increased in the last 15 years.	Greater awareness has not (yet) led to fundamental changes in pest and pesticide management.	Social media allow better targeting of information.	Ensure that awareness effectively translates into changes in policy and behaviours.
Training on judicious pesticide use	Increases knowledge and awareness about good practices and risks.	Often does not improve the behaviours of pesticide users.	Integration into broader policy measures to reduce risks posed by pesticides.	Avoid judicious pesticide training being provided in isolation from that in IPM.
Training in biointensive integrated pest management (IPM)	Leads to changes in farmers' behaviours which reduce risks of and reliance on pesticides.	Relatively expensive, so that upscaling has been constrained.	Integration into broader policy measures to reduce risks posed by pesticides. Combine with modern technologies to provide information and maintain contact.	Mobilize long-term funding. Need for long-term political commitment.

**Table 4 Engineering controls and technologies that can be used to reduce the environmental and health risks of pesticides: strengths, limitations, opportunities and challenges**

Measure	Strengths	Limitations	Opportunities	Challenges
Engineering controls	Risk reduction is integrated into the application equipment. Direct reduction of environmental and human exposure.	Increases costs of equipment.	Greater use of these technologies may reduce costs and increase availability.	Developing and marketing effective engineering controls appropriate for application methods used in low- income and middle-income countries.
Precision spraying	Optimizes use of pesticides. May directly reduce environmental and human exposure.	Significantly increases costs of equipment and application. May be dependent on external technical inputs (e.g. remote sensing data).	Greater use of these technologies may reduce costs and increase availability.	Providing affordable access to these technologies by smallholder farmers.
Personal protective equipment (PPE)	Direct reduction of environmental and human exposure. Relatively cheap and easy to use.	Not worn because uncomfortable, expensive or unavailable. May lead to unsafe practices if seen as offering complete protection.	Voluntary standards and certification systems require use of appropriate PPE.	Creating a culture in which PPE use is standard. Developing affordable, effective and comfortable PPE, particularly for use in low- and middle- income countries.

sustainable pest and pesticide management (Table 3). However, training and awareness building need to be combined with other policy measures to be successful in the long run (see Chapter 6.2.3).

### Engineering controls and technology

Numerous engineering controls and technologies can be used to reduce the environmental and health risks of pesticides. They include closed and ventilated tractor cabins, closed circuit tank filling and rinsing systems, and drift-reducing nozzles. Precision spraying and personal protective equipment are also used to reduce these risks (see Chapter 6.2.4).

### The effectiveness of current pesticide risk reduction approaches and measures

The effectiveness of many current pesticide risk reduction approaches and measures has been limited so far, particularly in low- and lower-middle-income countries. The most successful ones have mainly been successful in high-income and, to a lesser extent, middle-income countries (Table 5).

Availability of resources (financial, technical, human, information) is a critical variable determining the success of specific risk reduction options. Risk reduction measures that have been effective in high-income or middle-income countries will not necessarily be effective in

**Table 5 Effectiveness of pesticide risk reduction measures during the last two decades and overall trend, with a focus on low and lower-middle income countries.**

Measure	Effectiveness in reducing environmental and human health and risks			Overall trend
	High	Moderate	Limited	
<b>Regulatory measures</b>				
National pesticide legislation	H	M, L		↑
Pest and pesticide management policy		H	M, L	↑
Control and enforcement		H	M, L	↓
International conventions		M, L	H	↔
Voluntary international instruments		M, L	H	↔
Regional instruments and mechanisms		H, M, L		↑
HHP risk reduction		H, M, L		↔
Pesticide registration	H	M, L		↑
Post-registration monitoring		H	M, L	↔
<b>Economic measures</b>				
Pesticide subsidies		Not evaluated		
Pesticide taxes		H	M, L	↑
Private standards		Not evaluated		
<b>Training and awareness building</b>				
Awareness about pesticide risks		H, M	L	↔
Training and extension		H	M, L	↓
<b>Engineering controls</b>				
Spray technology		H, M	L	↑
PPE		H	M, L	↔

Trend: ↑ = improved; ↓ = declined; ↔ = unchanged

H= high income countries, M= middle income countries, L= low income countries

countries, communities or situations where resources are inadequate (see Chapter 6.2.5).

### Options for actions: strengthening pesticide management

Numerous measures are being taken in countries to promote sound management of pesticides and reduce their risks to the environment and health. Nevertheless, the degree to which such measures have been implemented or have been successful varies greatly among countries and regions. A diversity of choices and levels of progress provides opportunities to draw lessons from countries that have implemented measures with more or less success.

Depending on the degree of current implementation – and local regulatory, economic and cultural situations – countries may choose to develop and adopt specific measures. However, experience has shown that it is essential for a coherent and comprehensive set of measures to be based on a concrete policy vision if they are to be effective (see Chapter 6.3).

### Strengthening governance of the production, trade and use of pesticides

- **Elaborate and implement national sustainable pest and pesticide management policies**

By adopting a national pest and pesticide management policy, sound management of pesticides can be placed and/or maintained on the national government's policy agenda. Such a policy should define clear objectives and targets for pest and pesticide management within a foreseeable time period, and be aimed at promoting sustainable pest management and reducing pesticide risks. This can be achieved through a stand-alone pesticide management policy which includes pesticides, but also by using other approaches to pest management or by incorporating elements of such policies in national legislation, regulations or policies on related topics (see Chapter 3.4.5). All stakeholders, including private sectors, need to be involved in elaborating, implementing and monitoring this policy in order to secure wide support for its objectives and measures. Such a

policy needs to be put into practice through effective legislation and their enforcement.

- **Develop and update national pesticide legislation to include all elements of the pesticide life cycle**

Most countries have adopted dedicated pesticide legislation. In principle, this legislation should cover all types of pesticides and all aspects of the pesticide life cycle in order to further strengthen the legal basis for sound pesticide management. This could involve ensuring the inclusion of essential elements such as administration, registration, import and export, licensing, packaging and labelling, use, advertising, storage, transport and disposal, information collection, monitoring and incident reporting, inspection, and offences and penalties.

It is crucial that pesticide legislation be harmonized with national environmental, agricultural, health and economic regulations and policies aimed at pest and chemicals management, and that policy incoherence is avoided. To accomplish this, a national regulatory framework for control of pesticides may encompass a much broader set of legislation (e.g. legislation on environmental protection, public and occupational health, food safety, water, wildlife, plant protection and general chemicals management) than that which only directly addresses pesticides (see Chapter 3.4.1).

- **Enhance enforcement capacity to bolster effective implementation of national legislation**

In many countries there is an urgent need to increase the effectiveness of the inspection and control of pesticide-related activities during manufacturing, importation, distribution, sales, disposal, and use. Ways to increase effectiveness include strengthening inspection services, tightening collaboration with other law enforcement entities, and establishing laboratory capacity for pesticide quality control. In addition, a culture of compliance by all stakeholders should be cultivated, for example through information exchange, compliance incentives,

and appropriate forms of self-certification. Increased effectiveness of inspections and enforcement can be achieved by developing guidance and knowledge products with respect to what is required for compliance and increasing awareness in the regulated community. There is also a need to increase government capacity and enable regulatory entities to effectively carry out inspections, and to prosecute and adjudicate violations of pesticide legislation (see Chapter 3.4.5).

- **Establish or strengthen regional collaboration in pesticide management and, where relevant, harmonize pesticide legislation and standards regionally**

Regional collaboration can be an effective way to address transboundary or regional issues related to pesticides, such as cross-border trade in both legal and illegal pesticides, efficacy and residue testing of pesticides, pesticide residues in regionally traded commodities, pesticide pollution of transboundary watersheds, and information sharing on the observed efficacy and effects of pesticides and alternative pest management options. The regionalization of activities may include collaboration on the evaluation, authorization, inspection and control of pesticides and may occur through simple information exchange mechanisms or through more complex common decision-making. Regional collaboration can enhance the possibilities to control cross-border (illegal) trade in pesticides.

Regional harmonization of pesticide legislation goes a step further than collaboration. While more complex to establish and implement, regional harmonization can be beneficial for governments as well as the private sector, particularly in areas such as pesticide registration, pesticide quality standards, maximum residue levels (MRLs), and the control of illegal trade in pesticides. Regions may choose, for example, to harmonize their pesticide testing protocols, set up regional pesticide management action plans or introduce regional pesticide registration (see Chapter 3.3).

### **Strengthening monitoring of pesticide use and effects**

- **Collect statistics on the manufacturing, importation and sales of pesticides**

Monitoring pesticides' use and effects is critical to inform decision-making and policy development. Countries should consider establishing or strengthening, as a minimum, the collection of national statistics on manufacturing, importation and sales of pesticides. One key area to achieve this would be to include information collection in pesticide legislation. Specifically designating powers and responsibilities, including the ability to impose reporting requirements on manufacturers, importers, distributors and sellers of pesticide (see Chapter 3.4.1). Where possible, data on the use and disposal of pesticides should be compiled. After a pesticide is marketed, data collection and assessment may take place through regular monitoring, specific scientific studies, or feedback about incidents (see Chapter 4.2)

- **Establish pesticide residue monitoring systems and poison centres**

Countries may consider establishing, where they do not exist, national pesticide residue monitoring programmes for food, feed and drinking water. Although more complex, countries should also consider establishing post-registration monitoring of pesticides and their transformation products in the environment, especially in areas where there is high use intensity. In addition, national or regional poison centres that operate effectively are essential to better understand the health effects of pesticide use (see Chapter 4.4.2).

- **Ensure feedback into policy- and decision-making**

An analysis and reporting system needs to be put into place to ensure that the results obtained by monitoring and surveillance will inform policy- and decision-making on the authorization and use of pesticides. For example, post-registration monitoring and studies that complement prospective risk

assessments are important tools, especially since data on environmental settings and human populations can only become available after the market authorization of a compound. Pesticide registrations should be subject to a periodic review process for reauthorization if consecutive evaluations show that use of a pesticide under local conditions results in unacceptable risks based on the outcomes of post-registration monitoring and studies (see Chapter 4.2).

### Strengthening pesticide evaluation

- **Develop more integrated approaches to pesticide evaluation**

Pesticides are currently evaluated on their individual merits and risks. If a pesticide is found to be effective and does not pose unacceptable risks, it will generally be authorized for use. However, its risks and benefits compared to those of other pesticides or pest management approaches are not assessed, nor is its contribution to the long-term sustainability of pest or vector management.

This approach to pesticide registration can be transformed to promote broader sustainable pest management solutions. Alternative pest management options should be evaluated as part of the decision-making process, along with their environmental and economic impacts. Evidence-based and interdisciplinary decision-making should drive pest management choices, while explicitly taking into account uncertainties and knowledge gaps in a precautionary manner (see Chapter 4.4).

- **Establish robust pesticide risk assessment methods for low- and middle-income countries**

Since the human and financial resources available for pesticide evaluation are limited in many low- and middle-income countries, the extensive pesticide risk assessment approaches developed by some high-income countries generally cannot be applied there. There is an urgent need to develop robust and pragmatic environmental and human

health risk assessment methods applicable to conditions of use in major world regions, with a focus on tropical, sub-tropical and semi-arid regions. This need may be addressed by extrapolating existing methods for use in neglected ecosystems and regions (see Chapter 4.4). Particular attention should be given to vulnerable groups and specific risks related to gender

- **Optimize resources for pesticide evaluation**

To optimize the use of limited resources for pesticide evaluation and minimize duplication of work, further internationalization of efficacy and risk assessments is needed: evaluate hazards globally – assess efficacy and risks regionally – authorize pesticides nationally/regionally.

Pesticide hazards are typically independent of use conditions. They can therefore be evaluated globally. Pesticide efficacy and risks are influenced by conditions of use, as well as by environmental and agronomic circumstances, but they can be evaluated on a regional or (agro-)ecosystem basis rather than repeatedly at the national level. Registration decisions will also be influenced by the economic and social circumstances in which a pesticide is being used. Although based on international or regional efficacy, hazard and risk assessments, these decisions are therefore best taken at the national or regional levels (see Chapter 6.3.3).

- **Fill gaps for pesticide risk assessment**

Environmental and human health risk assessment has greatly improved in the past decades. Nevertheless, evaluating certain pesticide risks requires further scientific inputs, including the environmental and human health risks of pesticide mixtures and of endocrine disruptors, pesticides' health effects during child development, and their environmental risks in (sub-)tropical and (semi-)arid regions. Other principal directions for improving pesticide environmental and human health risk assessments are proposed in Chapters 4.3.7 and 4.4.8.



- **Increase transparency in decision-making**

In a number of recent cases, confusion has occurred as a result of apparent inconsistencies in evaluations conducted by different regulatory and scientific bodies. This has partly been due to use of different data sets and lack of access by non-regulators to data considered confidential.

To maintain public trust in the independence and comprehensiveness of regulatory risk assessments, there is a need to redefine the mechanisms that ensure the confidentiality of business information, but also to ensure public access to and third-party verification of environmental and human health information. These may be embedded in the legislation through, for example, registration and information collection, monitoring and incident reporting (see Chapter 3.4.1)

### **Innovate pest management through targeted research and development (R&D)**

- **Promote multi-stakeholder innovation**

Through the identification, development and implementation of innovative, context-appropriate and cost-effective technologies for pest and vector management requires collaboration between farmers or other pesticide users, public research bodies and the private sector. Such collaboration should not be limited to new pest control products. It can be broadened to innovative pest management approaches, including associated new skills that need to be adopted by farmers and other pesticide users. This can lead to more successful reductions in environmental and human health risks as a result of reduced application of pesticides, expanded use of reduced risk products, improved pesticide application practices, or better use of precautionary measures.

- **Develop low-risk pest control technologies**

Public and private sector actors should prioritize and facilitate the development of low-risk pesticides and bioprotectants.

This could include fast-track regulatory procedures, but also the establishment of local production facilities for beneficial macroorganisms and biopesticides, as well as services for the placement and monitoring of non-chemical pest control systems (e.g. traps, robotics, predator release) (see Chapter 2.7).

Innovative pest management technologies, such as RNAi for gene silencing in pests or CRISPR for breeding disease and pest resistant crops, may yield promising pest management approaches. They should be evaluated for efficacy and safety, as well as for access by smallholder farmers. More efficient pesticide application technologies, which reduce pesticide use and risks, also require further investment in R&D.

- **Assess costs and benefits**

There is an urgent need to conduct comprehensive assessments of all economics variables associated with the use of pesticides, including direct and indirect costs and benefits, with the aim of designing pest management strategies that are cost-effective at both the private and societal levels. Studies should also take into account other pest management options or the costs of externalities. For example, assessments may be made on the economic benefits of pesticide use at either individual pesticide level or a larger geographical scale as well as more comparisons between the overall costs of pesticide use with their estimated benefits (see Chapters 5.3.1 and 5.3.2).

- **Regularly review existing knowledge**

To make better use of the large body of research that continues to be generated on the efficacy and risks of pesticides, there is a need for regular systematic reviews of new knowledge and insights. Sound scientific approaches should be applied in order to conduct such reviews, ensure the quality of the data involved, and ensure the inclusion of these reviews in the regulatory (re-)evaluations of pesticides. For example, more systematic reviews on pesticide risks and their mitigation

options can be carried out (see Chapters 4.3.7 and 4.4.8).

### Inform and educate for change

- **Ensure independent information provision to farmers and other pesticide users**

To allow farmers and other pesticide users to make informed and objective decisions about pest management options, public agricultural extension systems and other independent advisory services need to be strengthened further. Integrated pest management (IPM) and integrated vector management (IVM) should be promoted through the training of agronomists, extension agents, input distributors and farmers.

Participatory and experience-based learning has been shown to be effective in ensuring the long-term adoption of sustainable behaviours and technologies, with specific attention

given to building the capacities of youth and women. Better use can also be made of digital technology and social media to provide information and complement education and training, while ensuring the inclusion of marginalized groups.

- **Include sustainable pest management in educational curricula**

Sustainable agriculture, agroecology, integrated pest management (IPM) and integrated vector management (IVM) could be included in the curricula and courses of agricultural schools, universities and other relevant training providers to a much greater extent. A highly participatory model which has been applied to build capacity in IPM management is farmer field schools (see Chapter 2.7.21).

Training in IPM, IVM and biocontrol should be considered a fundamental requirement for licensing of pest control operators.



- **Train health care and environmental professionals about pesticide risks**

Health care professionals need to be prepared to diagnose and treat cases of pesticide poisoning, particularly in areas where there is high pesticide use. Furthermore, environmental professionals (e.g. those engaged in carrying out environmental inspection and monitoring, or staff at watershed authorities) should be trained on the identification and remediation of pesticides' environmental effects (see Chapters 4.3 and 4.4).

All environmental and human health incidents documented by health care professionals should be reported, so that they feed back into the pesticide decision-making process.

### **The need for policy coherence**

Many strategies, programmes and projects have been developed and implemented during the last few decades to strengthen pest and pesticide management in all regions of the world. However, they have often addressed only a specific aspect of pest or pesticide management such as updating pesticide legislation, promoting integrated pest management (IPM) or biocontrol, strengthening pesticide registration, upgrading pesticide residue laboratories, disposing of obsolete pesticide stocks, training farmers in good agricultural practices, or transforming pesticide taxes or subsidies.

While such activities individually may have been quite successful in most parts of the world, they have not fundamentally changed how pests are managed or reduced the risks posed by pesticides. For example, pesticide use intensity is increasing, pesticide residues are ubiquitous in the environment, pesticide resistance continues to increase, occupational pesticide poisoning still occurs, surface water and groundwater are polluted by pesticides, and unanticipated environmental and health effects of pesticides are observed after the pesticides are authorized for use.

There is a need for integrated national and regional policies which address all aspects of

pest management and aim to make it sustainable in the long term. Such policies, which have been rare so far, need to combine regulatory and economic measures, ensure engagement to provide independent and relevant information, find effective ways to reach and train farmers and extension staff, develop innovative technologies accessible to stakeholders, and level the economic playing field for low-risk pesticides and pest management approaches. By their nature, these policies must be interdisciplinary, inter-ministerial and multi-stakeholder.

Pesticide risk reduction policies require an intelligent combination of measures which should be implemented in parallel or consecutively to achieve the goals that have been established. Integrated, more holistic approaches which reduce reliance on pesticide use are needed, including measures and incentives from the local farm level to the national (and even international) levels. Such approaches should set clear goals and targets, identify measures that contribute to achieving these targets, and include an assessment of measures that may be counterproductive.

## **5.2 Fertilizers**

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" (OECD 2018). 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.

### **An assessment of current fertilizer risk reduction measures**

Current measures used to minimize the environmental and health risks of fertilizers

largely look to regulatory and market-based approaches; education, training and awareness building; and research and development (R&D) (see Chapter 11.2).

### Regulatory measures

International conventions and regional agreements are frequently a basis for measures taken at the national level, including fertilizer evaluation, registration and labelling as well as control, enforcement and monitoring (Table 6).

Measures at all levels of decision-making should be based on scientific evidence and the precautionary principle (see Chapter 11.2.1).

### Market-based measures

The market-based measures used to reduce the environmental and health risks of fertilizers include taxes, subsidies, grants, and commodity price support for harvested produce. This report mainly focuses on subsidies and taxes (Table 7) (see Chapter 11.2.2).

**Table 6 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 8.2)	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 8.4)	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 8.5)	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 8.5)	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. There may be 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 8.5)	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.

**Table 7 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 8.5)	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 of successful countries can benefit other countries. More successful when combined with other policy measures.	Funds may be lacking. Subsidized fertilizers 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 8.5)	Fertilizer taxes can reduce fertilizer use and pollution. Tax credits (e.g. for organic inputs) can encourage their use.	Have had limited success. Are mostly designed to raise revenues, 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.

### Training and awareness building

A key objective of agriculture-related educational measures is to equip knowledge disseminators with appropriate knowledge and tools (Table 8). However, educational programmes can have limitations. For example, not all of them have an up-to-date curriculum addressing environmental issues.

An informed public can push for development and implementation of environmental policies. On the other hand, lack of adequate knowledge sometimes discourages the adoption of some policies; for example, consumers may reject food grown with recycled nutrients (see Chapter 11.2.3).

**Table 8 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.	Declining 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.	Governments and donors may be unwilling to invest more in extension services.

Measure	Strengths	Limitations	Opportunities	Challenges
Application of environmental measures by farmers	Adoption can contribute to a 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, 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 into a 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.

### 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 9) (see Chapter 11.2.4).

**Table 9 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 policies.	Research is costly and funds are sometimes lacking. Donor fatigue. Research priorities may differ between a country and donor.
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 the International Nitrogen Institute (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.

## Options for actions: strengthening fertilizer management

Some of the actions taken to reduce the environmental and health risks of fertilizers may require adjustments to achieve sustainable fertilizer use and management. A brief description of actions within the life cycle management of fertilizers is presented below, with options for priority actions based on the outcome of analyses of information presented in the report (see Chapter 11.3).

### 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 ones, 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 (see Box 8.5-1 in Chapter 8). 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 in Chapter 8).

- **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.

Increased effectiveness of inspections and enforcement can be achieved by developing guidance and knowledge products on what is required for compliance and conducting awareness for the regulated community. Furthermore, by increasing government capacity and enabling regulatory institutions to effectively carry out inspections, prosecute and adjudicate violations of fertilizers legislation.

- **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.

The regionalization of activities may include collaboration on the evaluation, authorization, inspection and control of pesticides and may occur through simple information exchange mechanisms or through more complex common decision-making. Regional collaboration can enhance the possibilities to control cross-border (illegal) trade in fertilizer.

- **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).

#### **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 for 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.

#### **Innovative 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.

### 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

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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 information and communications technology (ICT) and social media is increasing even in low- and middle-income countries, although the increase is less in the case of 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 low- and middle-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.

### **The need for policy coherence**

- **Conventions and policy instruments**

Many international and regional initiatives are already contributing (or have the potential to contribute) to the reduction of pollution from fertilizers (see Chapters 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 2017b) 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. For example, both nitrogen and phosphorus contribute to pollution in the aquatic environment (Chapter 9.3.3) and can be recycled together (Chapter 7.3). Gu *et al.* (2018) argued that it is crucial to

consider carbon sinks, which are necessary to reduce atmospheric carbon dioxide (CO<sub>2</sub>) concentrations, in addressing nitrogen pollution since large reductions of the latter may reduce the size of the 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 [International Nitrogen Management System] 2019) (Chapter 11.3).

# Transformative actions to minimize the adverse environmental and health impacts of pesticides and fertilizers



6

Priority transformative actions to minimize the adverse environmental and health impacts of pesticides and fertilizers have been identified through consultations with government experts, independent scientists, experts from intergovernmental organizations, and other stakeholders from the public and private sector. The identification of these transformative actions is based on the impacts they are expected to have on the sustainability of pesticide and fertilizer use; the degree to which they would minimize adverse impacts; and their interconnection with the SDGs and associated global policies.

Current and projected patterns of pesticide and fertilizer use are not sustainable. The projected growth of pesticide and fertilizer markets, together with prevailing deficiencies in management systems, will result in greater adverse impacts and more inefficient nutrient use in coming years unless a fundamental change takes place. Business-as-usual is not an option.

There is a need for transformative actions and for scaling up changes. The proposed transformative actions may not be applicable globally. In addition, specific conditions in countries and regions need

to be considered. These include, but are not limited to, differences in economic situations, agroecological conditions, past histories of sustainable pest and nutrient management, cultural and gender aspects, existing policies and legislation, and the effectiveness of their implementation.

The 17 Sustainable Development Goals (SDGs) are central to the identification of options for actions which could be taken by governments and other stakeholders. Effective implementation of these actions can be expected to contribute to meeting several SDG targets. For pesticide and nutrient management to become sustainable in the long run, the actions proposed in the report need to be integrated effectively into the implementation of relevant SDGs, just as implementing the SDGs should be addressed in an integrated, indivisible manner. Joint commitment by all stakeholders at the global level is required in order to achieve the impact expected. Deliberations of UNEA and other international bodies on the specific roles and responsibilities of stakeholders have identified priorities for pathways to achieve the SDGs (see Chapter 12.1).

## 6.1 Priority transformative actions

### 1. Incentivize healthy and sustainable consumer choices and consumption. Options include:

- ▶ Promote consumption of food, feed and fibres which have been produced in a sustainable manner, for example by facilitating market access, labelling schemes and other economic incentives throughout the value chain.
- ▶ Make consumers more aware of the pollution and health footprints of agricultural inputs, so that they can make informed choices (e.g. choose diets or clothing with smaller pollution footprints).
- ▶ Create attractive environments for the marketing of sustainably produced food, feed and fibres.
- ▶ Encourage the food, feed and textile industries to systematically integrate sustainability into their core business strategies and adopt sustainability standards.
- ▶ Encourage governments, educators and non-governmental organizations (NGOs) to provide product sustainability information,

for example through labelling or consumer campaigns.

- ▶ Ensure fair pricing systems for food, feed and fibres produced in a sustainable manner.

### 2. Fundamentally change crop production systems and adopt ecosystem-based approaches. Options include:

- ▶ Make sustainable agricultural intensification the central objective of national policies; promote agroecological approaches for crop, fibre and livestock production; discourage unsustainable agricultural practices.
- ▶ Effectively implement integrated pest management (IPM), integrated vector management (IVM), biocontrol and agroecology as the principal approaches to pest management.
- ▶ Support the development, availability and affordability of non-chemical alternative pest and vector control products and methods.
- ▶ Promote cropping systems that reduce the need for application of fertilizers (e.g. rotation of legumes with non-legumes) and exploit



synergies between cropping systems and livestock systems.

- ▶ Promote technologies and practices that reduce nutrient losses (e.g. integrated nutrient management, precision farming, enhanced efficiency fertilizers, biochar).

### 3. Promote circularity and resource efficiency. Options include:

- ▶ Implement more circular agricultural production systems that reduce the need for pesticides and synthetic fertilizers, based, for example, on crop rotation, nitrogen fixation, organic agriculture, crop varieties adapted to low-input agriculture, agroecology and conservation (zero-till) agriculture.
- ▶ Implement upstream quality control of fertilizers, pesticides and other pest management tools before they reach the market.
- ▶ Promote the use of modern technologies that contribute to improved pesticide and nutrient use efficiency, such as modelling to forecast pest development, adoption of economic thresholds, lure and kill and targeted application of pesticides, precision agriculture, improved pesticide formulations and application technologies, cloud-based tools for site-specific nutrient management, and enhanced efficiency fertilizers.
- ▶ Establish national systems for the collection and recycling of empty pesticide containers and environmentally sound treatment or disposal of other pesticide waste, particularly through public-private partnerships.
- ▶ Support recycling nutrients, for example through investing in the development of technology for nutrient recovery and treatment and in farmer training.
- ▶ Build consumer awareness of the safety of food grown using recycled nutrients (e.g. from household waste, treated sewage sludge) in countries where these nutrients are properly treated to ensure safety.

### 4. Use economic instruments and promote direct finance to create a level playing field for greener products and approaches. Options include:

- ▶ Sensitize policymakers about the importance of basic public funding as a requirement to ensure sustainable pesticide and nutrient management and to minimize indirect environmental, health and economic costs to society.
- ▶ Progressively internalize the environmental and human health costs of the use of pesticides and fertilizers in their pricing to level the economic playing field for greener/lower-risk products and approaches
- ▶ Apply smart economic policies (e.g. pricing policies for inputs and outputs) to achieve the right balance between food security and environmental health.
- ▶ Establish smart subsidies and taxes to promote sustainable pest and nutrient management, and remove counterproductive subsidies and tax exemptions.
- ▶ Redirect revenues from economic instruments towards supporting farmers in shifting to more sustainable practices, as well as towards research and development (R&D) that supports such shifts.
- ▶ Facilitate the marketing and use of technology packages that contribute to sustainable use of nutrients, lower-risk pesticides, bioprotectants and pest management instruments through discriminatory smart subsidies.

### 5. Adopt integrated and life cycle approaches for sound pesticide and fertilizer management. Options include:

- ▶ Transform the current focus on the regulation of pesticides and fertilizers to the promotion of sustainable and holistic approaches in pest and nutrient management solutions. Include all relevant sectors of government in the authorization process of pesticides and fertilizers.

- ▶ In addition to evaluating biological efficacy and environmental and human health risks, assess local needs for individual pesticide and fertilizers, as well as risks compared with those of other pest and nutrient management approaches, in the registration process.
  - ▶ Ensure evidence-based decision-making while taking account of the precautionary principle in situations where there are scientific complexity, uncertainty and knowledge gaps, in which case there may be a need to avoid or reduce potentially serious or irreversible threats to the environment and/or to human health.
  - ▶ Give the results of monitoring the efficacy and environmental and human health risks of pesticides and fertilizers a more explicit place in their (re-)authorization.
  - ▶ Facilitate registration of biological and other low-risk pesticides, for example by applying specific data requirements, reducing registration costs and fast-tracking their evaluations.
  - ▶ Consider, in policy decision-making, the complexity of quantifying the contribution of fertilizer use to risks, as pollutants associated with fertilizers can also be from other sources.
- 6. Strengthen standards and adopt corporate policies for sustainable supply chain management. Options include:**
- ▶ In the case of all actors in the supply chain, enhance information sharing to reveal information about upstream use of pesticides and fertilizers and harmonize approaches to sharing such information.
  - ▶ In the case of all actors in the agro-food system, widely adopt sustainability standards which address the use and impacts of pesticides and fertilizers.
  - ▶ In the case of all actors in the supply chain, adopt sustainable supply chain policies with attention given to minimizing unsustainable use of pesticides and fertilizers.
  - ▶ In the case of producers of pesticides and fertilizers, adopt extended producer responsibility policies to minimize their adverse impacts throughout the value chain.
  - ▶ Promote emerging good practices and initiatives with regard to sustainability standards and sustainable supply chain management where these ideas, practices and initiatives are less well known.

© Anne Wangalachi/CIHMYT. Drought tolerant maize route out of poverty for community-based seed producer Ruth Kamula, Kenya. CC BY-NC-SA 2.0



- ▶ Adopt proactive corporate measures aimed at making sustainable products and solutions available and becoming market leaders in this respect.

(See Chapter 12.2)

## 6.2 Ambitious collaborative action by all stakeholders is needed

### The time is right to scale up action to advance the sustainability of pesticides and fertilizers

The trends and opportunities presented in the Report on the Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them all point in one direction: advancing the sustainability of pesticides and fertilizers offers many benefits, environmental, social and economic. Governments (including regional and local authorities), private sector actors, research institutions and other stakeholders are encouraged to scale up their commitments and actions to advance the sustainable use of pesticides and fertilizers through collaborative actions.

Putting such collaboration into practice throughout global agri-food and public health systems is essential in order to create the transformative market shifts needed to advance the sustainability of agricultural production, products and services and minimize the adverse environmental and human health impacts of pesticides and fertilizers.

The public sector has an important role to play not only in regulating pesticides and fertilizers, but also in putting enabling policies and actions in place that foster the required transformation. Relevant measures include phasing out pesticides which pose high risks; supporting green and sustainable chemistry research; promoting sustainable agriculture, integrated pest and vector management, and agroecologically based approaches; raising awareness of the full cost of unsustainable practices; and providing fiscal incentives to foster market transformation (see Chapter 12.3).

### Developing road maps for sustainable pesticides and fertilizers management

Given the potential benefits of road maps, the 2019 Global Chemicals Outlook (GCO-II) (UNEP 2019) encouraged the development of country- and stakeholder-driven road maps on specific topics and by different stakeholder groups to support the implementation of sound management of chemicals and waste beyond 2020 and help monitor progress at all levels including the global level. These road maps could be developed on specific topics or themes, such as advancing adoption of sustainability standards, minimizing the adverse impacts of Highly Hazardous Pesticides (HHPs) in a particular context, or reducing pesticide and fertilizer run-off in a single watershed. They could also be elaborated at the national level to set specific goals and targets that need to be achieved in a country on its path towards sustainable pest and nutrient management.

What is required is leadership within relevant organizations. Such leadership can come from the top down through senior management or policymakers. It can also come from the bottom up through interested and committed individuals from all stakeholder groups (see Chapter 12.3).





# References

- 4R Nutrient Stewardship (2020). What are the 4Rs. <https://nutrientstewardship.org/4rs/>. Accessed 10 January 2022.
- Agrow (2019). Global crop protection market rose 6 per cent in 2018. 3 May 2019. *Agrow Agribusiness Intelligence*, London. <https://agrow.agribusinessintelligence.informa.com/AG031247/Global-crop-protection-market-rose-6-in-2018>.
- Amaral, M.J., Carretero, M.A., Bicho, R.C., Soares, A.M.V.M. and Mann, R.M. (2012). The use of a lacertid lizard as a model for reptile ecotoxicology studies: Part 1 – Field demographics and morphology. *Chemosphere* 87, 757-764. <https://doi.org/10.1016/j.chemosphere.2011.12.075>.
- American Geophysical Union (2020). Warming, acidic oceans may nearly eliminate coral reef habitats by 2021, 17 February. <https://news.agu.org/press-release/warming-acidic-oceans-may-nearly-eliminate-coral-reef-habitats-by-2100/>. Accessed 21 January 2021.
- Anderson, M., Clift, C., Schulze, K., Sagan, A., Nahrgang, S., Ouakrim, D. and Mossialos, E. (2019). *Averting the AMR Crisis: What Are the Avenues for Policy Action for Countries in Europe? Policy Brief 32*. World Health Organization/European Observatory on Health Systems and Policies. <https://www.ncbi.nlm.nih.gov/books/NBK543406/>.
- Attina, T.M., Hauser, R., Sathyanarayana, S., Hunt, P.A., Bourguignon, J.P., Myers, J.P. et al. (2016). Exposure to endocrine-disrupting chemicals in the USA: A population-based disease burden and cost analysis. *The Lancet Diabetes and Endocrinology* 4(12), 996-1003. [https://doi.org/10.1016/S2213-8587\(16\)30275-3](https://doi.org/10.1016/S2213-8587(16)30275-3).
- Australian Pesticides and Veterinary Medicines Authority (2021). Regulatory operations. <https://apvma.gov.au/node/1062>.
- Bauer, S., Tsigaridis, K. and Miller, R. (2016). Significant atmospheric aerosol pollution caused by world food cultivation. *Geophysical Research Letters* 43, 5394-5400. <https://doi.org/10.1002/2016GL068354>.
- Bellmann, C., Lee, B. and Hepburn, J. (2019). *Delivering Sustainable Food and Land Use Systems: The Role of International Trade*. Hoffmann Centre for Sustainable Resource Economy, Chatham House. Delivering Sustainable Food and Land Use Systems: The Role of International Trade | Chatham House – International Affairs Think Tank.
- Bodirsky, B., Rolinski, S., Biewald, A., Weindl, I., Popp, A. and Lotze-Campen, H. (2015). Global food demand scenarios for the 21st century. *PLoS ONE* 10(11), e0139201. <https://doi.org/10.1371/journal.pone.0139201>.
- Boedeker, W., Watts, M., Clausing, P. and Marquez, E. (2020). The global distribution of acute unintentional pesticide poisoning: Results of a systematic review. *BMC Public Health* 20, 1875 (2020). <https://doi.org/10.1186/s12889-020-09939-0>.
- Bourguet, D. and Guillemaud, T. (2016). The hidden and external costs of pesticide use. *Sustainable Agriculture Reviews* 19, 35-120. [https://doi.org/10.1007/978-3-319-26777-7\\_2](https://doi.org/10.1007/978-3-319-26777-7_2).
- Boyd, I.L. (2018). An inside view on pesticide policy. *Nature Ecology and Evolution* 2(6), 920-921. <https://doi.org/10.1038/s41559-018-0557-8>.
- Brock, T.C.M., Alix, A., Brown, C.D., Capri, E., Gottesbüren, B.F.F., Heimbach, F. et al. (eds.) (2010). *Linking Aquatic Exposure and Effects – Risk Assessment of Pesticides*. European Union and Society for Environmental Toxicology and Chemistry (SETAC). Boca Raton, London and New York: CRC Press. <https://www.routledge.com/Linking-Aquatic-Exposure-and-Effects-Risk-Assessment-of-Pesticides/Brock/p/book/9781138112643>.
- Brühl, C.A., Schmidt, T., Pieper, S. and Alscher, A. (2013). Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline? *Scientific Reports* 3, 1135. <https://doi.org/10.1038/srep01135>.
- Cedrez, C., Chamberlin, J., Guo, Z. and Hijmans, R. (2020). Spatial variation in fertilizer prices in Sub-Saharan Africa. *PLoS ONE* 15(1), e0227764. <https://doi.org/10.1371/journal.pone.0227764>.
- Chorus, I. and Welker, M. (eds.) (2021). *Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring and Management*. 2nd edition. <https://www.taylorfrancis.com/books/oa-edit/10.1201/9781003081449/toxic-cyanobacteria-water-ingrid-chorus-martin-welker>.
- Cloyd, R.A. (2012). Indirect effects of pesticides on natural enemies. In *Pesticides – Advances in Chemical and Botanical Pesticides*. Soundararajan, R.P. (ed.). IntechOpen. Chapter 6. <https://doi.org/10.5772/48649>.
- CropLife International (2021). Anti-counterfeiting. <https://croplife.org/crop-protection/anti-counterfeiting/>. Accessed 10 January 2022.
- Danish Environmental Protection Agency (2017). *Pesticidstrategi 2017-2021* (Pesticide strategy 2017-2021). <https://mst.dk/media/141516/pesticidstrategi2017-2021.pdf>.
- Data Bridge Market Research (2020). Animal feed market size, share outlook by 2027: Competitors' new strategies, growth, opportunities and techniques development analysis with current and future industry figures, 15 September. <https://www.globenewswire.com/fr/news-release/2020/09/15/2094056/0/en/Animal-Feed-Market-Size-Share-Outlook-by-2027-Competitors-New-Strategies-Growth-Opportunities-and-Techniques-Development-Analysis-with-Current-and-Future-Industry-Figures.html>. Accessed 6 February 2021.
- de Paz, J., Delgado, J., Ramos, C., Shaffer, M. and Barbarick, K. (2009). Use of a new GIS nitrogen index assessment tool for evaluation of nitrate leaching across a Mediterranean region. *Journal of Hydrology* 365(3-4), 183-194. <https://doi.org/10.1016/j.jhydrol.2008.11.022>.

- DunhamTrimmer (2019). *DunhamTrimmer's Global Biocontrol Market: Overview, Trends, Drivers and Insights. Presentation. 2019*. Lakewood Ranch, FL: DunhamTrimmer LLC. [http://dunhamtrimmer.com/wp-content/uploads/2019/05/TOC-DT\\_Global\\_Biocontrol\\_Overview\\_Links.pdf](http://dunhamtrimmer.com/wp-content/uploads/2019/05/TOC-DT_Global_Biocontrol_Overview_Links.pdf).
- Elamin, N.E.A. and Fernandez de Cordoba (2020). *The Trade Impact of Voluntary Sustainability Standards: A Review of Empirical Evidence*. United Nations Conference on Trade and Development (UNCTD) Research Paper No. 50. [https://unctad.org/system/files/official-document/ser-rp-2020d9\\_en.pdf](https://unctad.org/system/files/official-document/ser-rp-2020d9_en.pdf).
- Elibariki, R. and Maguta, M.M. (2017). Status of pesticides pollution in Tanzania – A review. *Chemosphere* 178, 154-164. <https://doi.org/10.1016/j.chemosphere.2017.03.036>.
- European Commission (2017). *A Study on the Effect of Listing of Chemicals in Annex III to the Rotterdam Convention. Final Report*. <http://www.pic.int/Implementation/EnhancingtheeffectivenessoftheConvention/Impactsoflicensingchemicals/tabid/7649/language/en-US/Default.aspx>.
- European Commission (2020b). Farm to fork strategy – for a fair, healthy and environmentally-friendly food system. [https://ec.europa.eu/food/farm2fork\\_en](https://ec.europa.eu/food/farm2fork_en). Accessed 15 November 2020.
- European Commission (n.d.) *Major Accident Prevention and Preparedness: Major Accidents Involving Fertilizers*. Lessons Learned Bulletin No. 5. [https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/mahb\\_bulletin\\_no5\\_final\\_forthewebpdf](https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/mahb_bulletin_no5_final_forthewebpdf).
- European Food Safety Authority (2021). About us: Who we are, what we do. <https://www.efsa.europa.eu/en/aboutefsa>. Accessed 10 January 2022.
- European Parliament (2021). *The Use of Pesticides in Developing Countries and Their Impact on Health and the Right to Food*. Directorate-General for External Policies. <https://www.europarl.europa.eu/cmsdata/219887/Pesticides%20health%20and%20food.pdf>.
- Fertilizers Europe (2022). Fertilizers Europe Product Stewardship Program. <https://www.fertilizerseurope.com/productstewardship2021/>. Accessed 10 January 2022.
- Food and Agriculture Organization of the United Nations (2015). *Status of the World's Soil Resources: Main Report*. Rome. <http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/>.
- Food and Agriculture Organization of the United Nations (2019a). *The International Code of Conduct for the Sustainable Use and Management of Fertilizers*. Rome. <http://www.fao.org/3/ca5253en/CA5253EN.pdf>.
- Food and Agriculture Organization of the United Nations (2019b). FAOSTAT. Fertilizers by nutrient. <http://www.fao.org/faostat/en/#data/RFN>. Accessed 10 January 2022.
- Food and Agriculture Organization of the United Nations (2020a). FAOSTAT. Annual population. <http://www.fao.org/faostat/en/#data/OA>. Accessed 24 October 2020.
- Food and Agriculture Organization of the United Nations (2020b). FAOSTAT. Crops. <http://www.fao.org/faostat/en/#data/QC>. Accessed 24 October 2020.
- Food and Agriculture Organization of the United Nations (2020c). FAOSTAT. Fertilizers indicators. <http://www.fao.org/faostat/en/#data/EF>. Accessed 24 October 2020.
- Food and Agriculture Organization of the United Nations (2020d). FAOSTAT. Fertilizers by nutrient. <http://www.fao.org/faostat/en/#data/RFN>. Accessed 24 October 2020.
- Food and Agriculture Organization of the United Nations (2020d). Why a Global Soil Partnership? <http://www.fao.org/global-soil-partnership/about/why-the-partnership/en/>. Accessed 20 November 2020.
- Food and Agriculture Organization of the United Nations (2021a). FAOSTAT. Data: Pesticides use. <https://www.fao.org/faostat/en/#data/RP/visualize>. Accessed 10 January 2022.
- Food and Agriculture Organization of the United Nations (2021b). Global Soil Partnership. <http://www.fao.org/faostat/en/#data/RFN>. Accessed 10 January 2022.
- Food and Agriculture Organization of the United Nations (2021c). Global Soil Partnership: Regional Soil Partnerships. <https://www.fao.org/global-soil-partnership/regional-partnerships/en/>. Accessed 10 January 2022.
- Food and Agriculture Organization of the United Nations (2021d). The Joint FAO/WHO Meeting on Pesticide Residues (JMPR). <https://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/jmpr/en/>. Accessed 10 January 2022.
- Food and Agriculture Organization of the United Nations and World Health Organization (2014). *The International Code of Conduct on Pesticide Management*. Rome. <http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en/>.
- Food and Agriculture Organization of the United Nations and World Health Organization (2016). *International Code of Conduct on Pesticide Management: Guidelines on Highly Hazardous Pesticides*. Rome. <http://www.fao.org/3/a-i5566e.pdf>.
- Food and Agriculture Organization of the United Nations and World Health Organization (2019). *Global Situation of Pesticide Management in Agriculture and Public Health. Report of a 2018 WHO-FAO Survey*. Rome and Geneva. <https://apps.who.int/iris/handle/10665/329971>.
- Food and Agriculture Organization of the United Nations and World Health Organization (2020). *International Code of Conduct on Pesticide Management: Guidelines on Pesticide Legislation*. Second edition. Rome. <https://doi.org/10.4060/cb0916en>.

- Food and Agriculture Organization of the United Nations, International Fund for Agriculture, United Nations Children's Fund, World Food Programme and World Health Organization (2020). *The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets*. Rome: Food and Agriculture Organization of the United Nations. <https://doi.org/10.4060/ca9692en>.
- Gall, J., Boyd, R. and Rajakaruna, S. (2015). Transfer of heavy metals through terrestrial food webs: A review. *Environmental Monitoring and Assessment* 187, 201. <https://doi.org/10.1007/s10661-015-4436-3>.
- Garrigou, A., Laurent, C., Berthet, A., Colosio, C., Jas, N., Daubas-Letourneux, V. *et al.* (2020). Critical review of the role of PPE in the prevention of risks related to agricultural pesticide use. *Safety Science* 123, 104527. <https://doi.org/10.1016/j.ssci.2019.104527>.
- Glare, T., Caradus, J., Gelernter, W., Jackson, T., Keyhani, N., Köhl, J. *et al.* (2012). Have biopesticides come of age? *Trends in Biotechnology* 30(5), 250-258. <https://doi.org/10.1016/j.tibtech.2012.01.003>.
- Global Panel on Agriculture and Food Systems for Nutrition (2016). *The Cost of Malnutrition. Why Policy Action is Urgent. Technical Brief No. 3*. <https://www.glopan.org/cost-of-malnutrition/>.
- Global Partnership on Nutrient Management (2014). *Global Partnership on Nutrient Management (GPNM) Progress Report – December 2014*. <https://www.unenvironment.org/resources/report/global-partnership-nutrient-management-gpnm-progress-report-december-2014>.
- Government of France (2018). *Écophyto II+ : Reducing and Improving the Use of Plant Protection Products*. Ministère de la Transition écologique et solidaire. [https://ec.europa.eu/food/sites/food/files/plant/docs/pesticides\\_sup\\_nap\\_fra-ecophyto-2plus\\_plan\\_en.pdf](https://ec.europa.eu/food/sites/food/files/plant/docs/pesticides_sup_nap_fra-ecophyto-2plus_plan_en.pdf).
- Grandview Research (2017). *Agrochemicals market worth \$308.92 billion by 2025 | CAGR: 4.1%*. <https://www.grandviewresearch.com/press-release/global-agrochemicals-market>. Accessed 6 February 2021.
- Grandview Research (2021). *Natural Fibers Market Size, Share and Trends Analysis Report by Application, by Regional Outlook, by Competitive Strategies, and Segment Forecasts, 2019 to 2025*. <https://www.grandviewresearch.com/industry-analysis/natural-fibers-market>.
- Group of Chief Scientific Advisors (2018). *EU Authorisation Processes of Plant Protection Products – from a Scientific Point of View*. Scientific Advice Mechanism (SAM), Scientific Opinion 5. Directorate-General for Research and Innovation, European Commission, Brussels. <https://op.europa.eu/en/publication-detail/-/publication/5306df12-79b9-11e8-ac6a-01aa75ed71a1/language-en/format-PDF/source-94583924>.
- Gu, B., Ju, X., Wu, Y., Erisman, J., Bleeker, A., Reis, S. *et al.* (2018). Cleaning up nitrogen pollution may reduce future carbon sinks. *Global Environmental Change* 48, 56-66. <http://dx.doi.org/10.1136/oemed-2019-105880>. Accessed 10 January 2022.
- Guida, Y. de S., Meire, R.O., Torres, J.P.M. and Malm, O. (2018). Air contamination by legacy and current-use pesticides in Brazilian mountains: An overview of national regulations by monitoring pollutant presence in pristine areas. *Environmental Pollution* 242, Part A, 19-30. <https://doi.org/10.1016/j.envpol.2018.06.061>.
- Guglielmi, G. (2020) Why Beirut's ammonium nitrate blast was so devastating. *Nature*, 10 August. Accessed 28 December 2020. <https://www.nature.com/articles/d41586-020-02361-x>.
- Hvězdová, M., Kosubová, P., Košíková, M., Scherr, K.E., Šimek, Z., Brodský, L. *et al.* (2018). Currently and recently used pesticides in Central European arable soils. *Science of The Total Environment* 613-614, 361-370. <https://doi.org/10.1016/j.scitotenv.2017.09.049>.
- International Agency for Research on Cancer (2021). *IARC Monographs on the Identification of Carcinogenic Hazards to Humans*. <https://monographs.iarc.who.int>. Accessed 10 January 2022.
- International Fertilizer Association (2019). *Medium-Term Outlook for Fertilizers and Raw Materials Global Supply: 2019-2023*. Available to International Fertilizer Association members only.
- International Fertilizer Association (2021a). *Public Summary: Medium-Term Fertilizer Outlook 2021-2025*. <https://www.ifastat.org/market-outlooks>.
- International Fertilizer Association (2021b). *Fertilizers, for productive and sustainable agriculture systems*. <https://www.fertilizer.org>. Accessed 10 January 2020.
- Ilinova, A., Dmitrieva, D. and Kraslawski, A. (2021). Influence of COVID-19 pandemic on fertilizer companies: The role of competitive advantages. *Resources Policy* 71, 102019. <https://doi.org/10.1016/j.resourpol.2021.102019>.
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019). *Global Assessment Report on Biodiversity and Ecosystem Services*. <https://ipbes.net/global-assessment>.
- International Feed Industry Federation (2021). *Global feed statistics*. <https://iff.org/global-feed/statistics>. Accessed 6 February 2021.
- International Nitrogen Initiative (2014). *Kampala Statement-for-Action on Reactive Nitrogen in Africa and Globally*. [http://nitrogen.ipni.net/ipniweb/region/nitrogen.nsf/0/D51BE25E41D286D185257E7E00567292/\\$FILE/2013%20Kampala%20Statement.pdf](http://nitrogen.ipni.net/ipniweb/region/nitrogen.nsf/0/D51BE25E41D286D185257E7E00567292/$FILE/2013%20Kampala%20Statement.pdf).
- International Nitrogen Management System. *Nitrogen: Grasping the Challenge*. <https://www.inms.international/sites/inms.international/files/Nitrogen%20Grasping%20the%20Challenge%20%28Summary%20Version%29.pdf>.
- International Nitrogen Management System (2019). *Fourth Meeting of the International Nitrogen Management System (INMS-4). Summary of the High-Level Segment. 29-30 April 2019*. [https://www.inms.international/sites/inms.international/files/INMS-4%20Summary%20Report%20of%20high-level%20segment%20\(30%20July%202019\)%20\(002\).pdf](https://www.inms.international/sites/inms.international/files/INMS-4%20Summary%20Report%20of%20high-level%20segment%20(30%20July%202019)%20(002).pdf).

- International Trade Centre (2021). The state of sustainable markets 2021. <https://digital.intracen.org/state-sustainable-markets-2021/state-of-sustainable-markets-2021/>. Accessed 10 January 2022.
- Inter-Organization Programme for the Sound Management of Chemicals (2018). *Chemicals and Waste Management: Essential to Achieving the Sustainable Development Goals (SDGs)*. [http://www.who.int/iomc/ChemicalsandSDGs\\_interactive\\_Feb2018\\_new.pdf](http://www.who.int/iomc/ChemicalsandSDGs_interactive_Feb2018_new.pdf).
- Johnson, A. and Bruulsema, T. (2014). 4R nutrient stewardship for improved nutrient use efficiency. *Procedia Engineering* 83, 365-370. <https://doi.org/10.1016/j.proeng.2014.09.029>.
- Kanter, D., Zhang, X. and Mauzerall, D. (2014). Reducing nitrogen pollution while decreasing farmers' costs and increasing fertilizer industry profits. *Journal of Environmental Quality* 44(2), 325-335. <https://doi.org/10.2134/jeq2014.04.0173>.
- Khan, M., Mobin, M., Abbas, Z. and Alamri, S. (2018). Fertilizers and their contaminants in soils, surface and groundwater. In *The Encyclopedia of the Anthropocene. Volume 5: Contaminants*. Elsevier. Dellasala, D.A. and Goldstein, M. (eds). 225-240. <https://doi.org/10.1016/B978-0-12-809665-9.09888-8>.
- Kirchner, M., Jakobi, G., Körner, W., Levy, W., Moche, W., Niedermoser, B. et al. (2016). Ambient air levels of organochlorine pesticides at three high alpine monitoring stations: Trends and dependencies on geographical origin. *Aerosol and Air Quality Research* 16(3), 738-751. <https://doi.org/10.4209/aaqr.2015.04.0213>.
- Kopittke, P., Menzies, N., Wang, P., McKenna, B. and Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environmental International* 132, 105078. <https://doi.org/10.1016/j.envint.2019.105078>.
- Kovács-Hostyánszki, A., Li, J., Pettis, J., Settele, J., Aneni, T., Espíndola, A. et al. (2016). Drivers of change of pollinators, pollination networks and pollination. In *The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*. Potts, S.G., Imperatriz-Fonseca, V.L. and Ngo, H.T. (eds.). Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Chapter 2, 27-149. <https://ipbes.net/assessment-reports/pollinators>.
- Kubickova, B., Babica, P., Hilscherová, K. and Šindlerová, L. (2019). Effects of cyanobacterial toxins on the human gastrointestinal tract and the mucosal innate immune system. *Environmental Sciences Europe* 31(31), 1-27. <https://doi.org/10.1186/s12302-019-0212-2>.
- Krieger, R. (2010). *Hayes' Handbook of Pesticide Toxicology, Volumes 1 and 2*. 3rd edition. Krieger, R., Doull, J., van Hemmen, J., Hodgson, E., Maibach, H., Reiter, L., Ritter et al. (eds.). London: Academic Press. <https://www.elsevier.com/books/hayes-handbook-of-pesticide-toxicology/krieger/978-0-08-092201-0>.
- Laboureur, D., Han, Z., Harding, B., Pineda, A., Pittman, W., Rosas, C. et al. (2016). Case study and lessons learned from the ammonium nitrate explosion at the West Fertilizer facility. *Journal of Hazardous Materials* 308, 164-172. <https://doi.org/10.1016/j.jhazmat.2016.01.039>.
- Marlow, H., Hayes, W., Soret, S., Carter, R., Schwab, E. and Sabaté, J. (2009). Diet and the environment: Does what you eat matter? *The American Journal of Clinical Nutrition* 89(5), 1699S-703S. <https://doi.org/10.3945/ajcn.2009.26736Z>.
- Mateo-Sagasta, J., Zadeh, S. and Turral, H. (2018). *More People, More Food, Worse Water? A Global Review of Water Pollution from Agriculture*. Rome and Colombo: Food and Agriculture Organization of the United Nations and International Water Management Institute on behalf of the Water, Land and Ecosystems research program of the CGIAR. <http://www.fao.org/3/CA0146EN/ca0146en.pdf>.
- Mew, E.J., Padmanathan, P., Konradsen, F., Eddleston, M., Chang, S.-S., Phillips, M.R. and Gunnell, D. (2017). The global burden of fatal self-poisoning with pesticides 2006-15: Systematic review. *Journal of Affective Disorders* 219, 93-104. <https://doi.org/10.1016/j.jad.2017.05.002>.
- Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Washington, D.C.: Island Pres. <https://www.millenniumassessment.org/en/Reports.html>.
- Miller, C., Spiehs, M., Arthur, T., Woodbury, B., Cortus, C., Chatterjee, A. et al. (2019). Cropland amendment with beef cattle manure minimally affects antimicrobial resistance. *Journal of Environmental Quality* 48, 1683-1693. <https://doi.org/10.2134/jeq2019.02.0042>.
- Milner, A.M. and Boyd, I.L. (2017). Toward pesticidovigilance – Can lessons from pharmaceutical monitoring help to improve pesticide regulation? *Science* 357(6357), 1232-1234. <https://doi.org/10.1126/science.aan2683>.
- Mineau, P. and Whiteside, M. (2006). Lethal risk to birds from insecticide use in the United States – a spatial and temporal analysis. *Environmental Toxicology and Chemistry* 25(5), 1214-1222. <https://pubmed.ncbi.nlm.nih.gov/16704051/>.
- Mota-Sanchez, D. and Wise, J.C. (2019). Arthropod pesticide resistance database. *Michigan State University, East Lansing, United States*. <http://www.pesticideresistance.org>. Accessed 10 January 2022.
- National Research Council (2013). *Assessing Risks to Endangered and Threatened Species from Pesticides*. Washington, D.C.: National Academies Press. <https://doi.org/10.17226/18344>.
- Ntzani, E.E., Markozannes, G., Tagas, C., Rizos, E. and Karalexi, M. (2020). Epidemiological evidence review report: Exposure to pesticides and fertilizers and human health – Part A. Department of Hygiene and Epidemiology, University of Ioannina School of Medicine, Ioannina, Greece. Supporting document to this review (*Environmental and Health Impacts of Pesticides and Fertilizers and Ways of Minimizing Them*).
- Ohlander, J., Fuhriemann, S., Basinas, I., Cherrie, J.W., Galea, K.S., Povey, A.C. et al. (2020). Systematic review of methods used to assess exposure to pesticides in occupational epidemiology studies, 1993-2017. *Occupational and Environmental Medicine* 77(6), 357-367. <http://dx.doi.org/10.1136/oemed-2019-105880>.

- Oliver, E. (2018). Growing importance of China and India in the global crop protection market. *Agribusiness Intelligence*, Informa.
- Organisation for Economic Co-operation and Development (2018). *Agricultural Risk Management and Resilience: A Holistic Approach*. Agriculture Policy Brief. [https://issuu.com/oecd.publishing/docs/agricultural\\_risk\\_management\\_and\\_re](https://issuu.com/oecd.publishing/docs/agricultural_risk_management_and_re).
- Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations (2018). *OECD-FAO Agricultural Outlook 2018-2027*. Paris: OECD Publishing and Rome: Food and Agriculture Organization of the United Nations. <http://www.fao.org/3/i9166en/i9166en.pdf>.
- Peng, W. and Berry, E. (2018). Global nutrition 1990-2015: A shrinking hungry, and expanding fat world. *PLoS ONE* 13(3): e0194821. <https://doi.org/10.1371/journal.pone.0194821>.
- Pietrzak, D., Kania, J., Malina, G., Kmiecik, E., and Wątor, K. (2019). Pesticides from the EU First and Second Watch Lists in the Water Environment. *Clean Soil, Air, Water* 47(7), 1800376. <https://doi.org/10.1002/clen.201800376>.
- Pittman, W., Han, Z., Harding, B., Rosas, C., Jiang, J., Pineda, A. and Mannan, S. (2014). Lessons to be learned from an analysis of ammonium nitrate disasters in the last 100 years. *Journal of Hazardous Materials* 280, 472-477. <https://doi.org/10.1016/j.jhazmat.2014.08.037>.
- Prüss-Ustün, A., Wolf, J., Corvalán, C., Bos, R. and Neira, M. (2016). *Preventing Disease through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks*. Geneva: World Health Organization. <https://www.who.int/publications/i/item/9789241565196>.
- Potts, S.G., Imperatriz-Fonseca, V.L. and Ngo, H.T. (eds.) (2016). *Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*. Bonn: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. <https://ipbes.net/assessment-reports/pollinators>.
- Pozzer, A., Tsimpidi, A., Karydis, V., de Meij, V. and Lelieveld, J. (2017). Impact of agricultural emission reductions on fine-particulate matter and public health. *Atmospheric Chemistry and Physics* 17, 12813-12826. <https://doi.org/10.5194/acp-17-12813-2017>.
- Rico, A., Dafouz, R., Vighi, M., Rodríguez Gil, J.L. and Daam, M.A. (2020). Use of post registration monitoring data to evaluate the ecotoxicological risks of pesticides to surface waters: A case study with Chlorpyrifos in the Iberian Peninsula. *Environmental Toxicology and Chemistry* 40(2), 500-512. <https://doi.org/10.1002/etc.4927>.
- Roberts, J. and Reigart, J.R. (2013). *Recognition and Management of Pesticide Poisonings*. Sixth edition. Washington, D.C.: United States Environmental Protection Agency. [https://www.epa.gov/sites/production/files/2015-01/documents/rmpp\\_6thed\\_final\\_lowresopt.pdf](https://www.epa.gov/sites/production/files/2015-01/documents/rmpp_6thed_final_lowresopt.pdf).
- Robin, D.C. and Marchand, P.A. (2018). Evolution of the biocontrol active substances in the framework of the European Pesticide Regulation (EC) No. 1107/2009. *Pest Management Science* 75(4), 950-958. <https://doi.org/10.1002/ps.5199>.
- Rodríguez Eugenio, N., McLaughlin, M. and Pennock, D. (2018). *Soil Pollution: A Hidden Reality*. Rome: Food and Agriculture Organization of the United Nations. <http://www.fao.org/3/i9183en/i9183en.pdf>.
- Rotterdam Convention (2017). *Study of Information on the Impacts of Listing Chemicals in Annex III to the Rotterdam Convention*. Conference of the Parties to the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. Eighth meeting Geneva, 24 April-5 May 2017. UNEP/FAO/RC/COP.8/INF/21. <http://www.pic.int/Implementation/EnhancingtheeffectivenessoftheConvention/Impactsoflistingchemicals/tabid/7649/language/en-US/Default.aspx>.
- Roubos, C.R., Rodriguez-Saona, C. and Isaacs, R. (2014). Mitigating the effects of insecticides on arthropod biological control at field and landscape scales. *Biological Control* 75, 28-38. <https://doi.org/10.1016/j.biocontrol.2014.01.006>.
- Sabaté, J. and Soret, S. (2014). Sustainability of plant-based diets: Back to the future. *The American Journal of Clinical Nutrition* 100 (supplement 1), 476S-482S. <https://doi.org/10.3945/ajcn.113.071522>.
- Sánchez-Bayo, F. and Wyckhuys, K. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation* 232, 8-27. <https://doi.org/10.1016/j.biocon.2019.01.020>.
- Sapbamrer, R. and Thammachai, A. (2020). Factors affecting use of personal protective equipment and pesticide safety practices: A systematic review. *Environmental Research* 185, 109444. <https://doi.org/10.1016/j.envres.2020.109444>.
- Sattler, C., Gianuca, A.T., Schweiger, O., Franzén, M. and Settele, J. (2020). Pesticides and land cover heterogeneity affect functional group and taxonomic diversity of arthropods in rice agroecosystems. *Agriculture, Ecosystems and Environment* 297, 106927. <https://doi.org/10.1016/j.agee.2020.106927>.
- Schäfer, R.B., Liess, M., Altenburger, R., Filser, J., Hollert, H., Roß-Nickoll, M., Schäffer, A. and Scheringer, M. (2019). Future pesticide risk assessment: Narrowing the gap between intention and reality. *Environmental Sciences Europe* 31(1). <https://doi.org/10.1186/s12302-019-0203-3>.
- Scientific Panel on Plant Nutrition (2021). A vision for responsible plant nutrition. <https://www.sprpn.org/vision-mission>. Accessed 10 January 2022.
- Sobota, D., Compton, J., McCrackin, M. and Singh, S. (2015). Cost of reactive nitrogen release from human activities to the environment in the United States. *Environmental Research Letters* 10, 1-13. <https://iopscience.iop.org/article/10.1088/1748-9326/10/2/025006/meta>.
- Stanton, R.L., Morrissey, C.A. and Clark, R.G. (2018). Analysis of trends and agricultural drivers of farmland bird declines in North America: A review. *Agriculture, Ecosystems and Environment* 254, 244-254. <https://doi.org/10.1016/j.agee.2017.11.028>.

- Statista (2021). Market value of biofuels worldwide in 2019 and 2024, 27 January. <https://www.statista.com/statistics/217179/global-biofuels-market-size/#:~:text=In%202016%2C%20the%20global%20market,higher%20prices%20for%20alternative%20fuels>. Accessed 6 February 2021.
- Stehle, S., Bub, S. and Schulz, R. (2018). Compilation and analysis of global surface water concentrations for individual insecticide compounds. *Science of The Total Environment* 639, 516-525. <https://doi.org/10.1016/j.scitotenv.2018.05.158>.
- Stehle, S. and Schulz, R. (2015). Agricultural insecticides threaten surface waters at the global scale. *Proceedings of the National Academy of Sciences of the United States of America* 112(18), 5750-5755. <https://doi.org/10.1073/pnas.1500232112>.
- Stockholm Resilience Centre (2021). Planetary boundaries. <https://www.stockholmresilience.org/research/planetary-boundaries.html>. Accessed 10 January 2022.
- Sutton, M.A., Bleeker, A., Howard, C.M., Bekunda, M., Grizzetti, B., de Vries, W., van Grinsven, H.J.M. et al. (2013). *Our Nutrient World: The Challenge to Produce More Food and Energy with Less Pollution. Global Overview of Nutrient Management*. Edinburgh: Centre for Ecology and Hydrology on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative. [https://www.researchgate.net/publication/283418805\\_Our\\_nutrient\\_world\\_The\\_challenge\\_to\\_produce\\_more\\_food\\_energy\\_with\\_less\\_pollution](https://www.researchgate.net/publication/283418805_Our_nutrient_world_The_challenge_to_produce_more_food_energy_with_less_pollution).
- Sutton, M.A., Howard C.M., Adhya T.K., Baker E., Baron J., Basir A., Brownlie W. et al. (2019). *Nitrogen: Grasping the Challenge. A Manifesto for Science-in-Action through the International Nitrogen Management System. Summary Report*. Edinburgh: Centre for Ecology and Hydrology on behalf of the International Nitrogen Management System (INMS). [https://papersmart.unon.org/resolution/uploads/nitrogen\\_grasping\\_the\\_challenge\\_1.9\\_summary\\_version.pdf](https://papersmart.unon.org/resolution/uploads/nitrogen_grasping_the_challenge_1.9_summary_version.pdf).
- Sutton, M.A., Raghuram, N. and Adhya, T. K. (lead authors). (2019). The nitrogen fix: From nitrogen cycle pollution to nitrogen circular economy. In *Frontiers 2018/19: Emerging Issues of Environmental Concern*. Nairobi: UNEP. 52-64. [https://wedocs.unep.org/bitstream/handle/20.500.11822/27543/Frontiers1819\\_ch4.pdf?sequence=1](https://wedocs.unep.org/bitstream/handle/20.500.11822/27543/Frontiers1819_ch4.pdf?sequence=1).
- Tang, Q., Ti, C., Xia, L., Xia, Y., Wei, Z. and Yan, X. (2019). Ecosystem services of partial organic substitution for chemical fertilizer in a peri-urban zone in China. *Journal of Cleaner Production* 224, 779-788. <https://doi.org/10.1016/j.jclepro.2019.03.201>.
- Tassin de Montaigu, C. and Goulson, D. (2020). Identifying agricultural pesticides that may pose a risk for birds. *PeerJ* 8, e9526. <https://doi.org/10.7717/peerj.9526>.
- Tayleur, C., Balmford, A., Buchanan, G.M., Butchart, S.H.M., Ducharme, H., Green, R.E. et al. (2017). Global Coverage of Agricultural Sustainability Standards, and Their Role in Conserving Biodiversity. *Conservation Letters* 10(5), 610-618. <https://doi.org/10.1111/conl.12314>.
- Topping, C.J., Aldrich, A. and Berny, P. (2020). Overhaul environmental risk assessment for pesticides. *Science* 367(6476), 360-363. <https://doi.org/10.1126/science.aay1144>.
- Townsend, A., Howarth, R., Bazzaz, F., Booth, M., Cleveland, C., Collinge, S. et al. (2003). Human health effects of a changing global nitrogen cycle. *Frontiers in Ecology and Environment* 1(5), 240-246. [https://doi.org/10.1890/1540-9295\(2003\)001\[0240:HHEOAC\]2.0.CO;2](https://doi.org/10.1890/1540-9295(2003)001[0240:HHEOAC]2.0.CO;2).
- Trasande, L., Zoeller, R.T., Hass, U., Kortenkamp, A., Grandjean, P., Myers, J.P. et al. (2015). Estimating burden and disease costs of exposure to endocrine-disrupting chemicals in the European Union. *Journal of Clinical Endocrinology and Metabolism* 100(4), 1245-1255. <https://doi.org/10.1210/jc.2014-4324>.
- Trasande, L., Zoeller, R.T., Hass, U., Kortenkamp, A., Grandjean, P., Myers, J.P. et al. (2016). Burden of disease and costs of exposure to endocrine disrupting chemicals in the European Union: An updated analysis. *Andrology* 4(4), 565-572. <https://doi.org/10.1111/andr.12178>.
- The Sustainability Consortium (2022). The Sustainability Consortium: Sustainable products for a sustainable planet. <https://sustainabilityconsortium.org>.
- United Nations Environment Programme (2017a). *United Nations Environment Assembly of the United Nations Environment Programme Third Session. Nairobi, 4-6 December 2017. 3/4. Environment and Health*. [https://wedocs.unep.org/bitstream/handle/20.500.11822/30795/UNEA3\\_4EN.pdf?sequence=1&isAllowed=y](https://wedocs.unep.org/bitstream/handle/20.500.11822/30795/UNEA3_4EN.pdf?sequence=1&isAllowed=y).
- United Nations Environment Programme (2017b). *Towards a Pollution-Free Planet: Background Report*. [https://wedocs.unep.org/bitstream/handle/20.500.11822/21800/UNEA\\_towardspollution\\_long%20version\\_Web.pdf?sequence=1&isAllowed=y/](https://wedocs.unep.org/bitstream/handle/20.500.11822/21800/UNEA_towardspollution_long%20version_Web.pdf?sequence=1&isAllowed=y/).
- United Nations Environment Programme (2019). *Global Chemicals Outlook II – From Legacies to Innovative Solutions: Implementing the 2030 Agenda for Sustainable Development*. <https://www.unep.org/resources/report/global-chemicals-outlook-ii-legacies-innovative-solutions>.
- United Nations Environment Programme and GRID-Arendal (2020). *The Illegal Trade in Chemicals*. <https://www.unep.org/resources/assessment/illegal-trade-chemicals>.
- United Nations Forum on Sustainability Standards (2021). What are Voluntary Sustainability Standards (VSS)? <https://unfss.org>. Accessed 10 January 2022.
- United States Environmental Protection Agency (2015). *Chemical Advisory: Safe Storage, Handling, and Management of Solid Ammonium Nitrate Prills*. [https://www.epa.gov/sites/production/files/2015-06/documents/an\\_advisory\\_6-5-15.pdf](https://www.epa.gov/sites/production/files/2015-06/documents/an_advisory_6-5-15.pdf).
- United States Environmental Protection Agency (2016). *Toxicological Review of Ammonia Noncancer Inhalation [CASRN 7664-41-7]*. <https://iris.epa.gov/static/pdfs/0422tr.pdf>.
- United States Environmental Protection Agency (2021). About EPA. <https://www.epa.gov/aboutepa>. Accessed 10 January 2022.

- van Grinsven, H., Holland, M., Jacobsen, B. and Klimont, Z. (2013). Costs and benefits of nitrogen for Europe and Implications for mitigation. *Environmental Science and Technology* 47, 3571-3579. <https://doi.org/10.1021/es303804g>.
- Vulliet, E., Tournier, M., Vauchez, A., Wiest, L., Baudot, R., Lafay, F. *et al.* (2014). Survey regarding the occurrence of selected organic micropollutants in the groundwaters of overseas departments. *Environmental Science and Pollution Research* 21(12), 7512-7521. <https://doi.org/10.1007/s11356-014-2619-z>.
- Wang, X., Wang, C., Zhu, T., Gong, P., Fu, J. and Cong, Z. (2019). Persistent organic pollutants in the polar regions and the Tibetan Plateau: A review of current knowledge and future prospects. *Environmental Pollution* 248, 191-208. <https://doi.org/10.1016/j.envpol.2019.01.093>.
- Wanzala, M. and Groot, R. (2013). *Fertilizer Market Development in Sub-Saharan Africa*. Paper presented to the International Fertiliser Society at a Conference in Windsor, United Kingdom (UK) on 24 May 2013. Leek, UK: International Fertilizer Society. <https://fertiliser-society.org/store/fertiliser-market-development-in-sub-saharan-africa/>.
- Ward, M.H., Jones, R.R., Brender, J.D., de Kok, T.M., Weyer, P.J., Nolan, B.T. *et al.* (2018). Drinking water nitrate and human health: An updated review. *International Journal of Environmental Research and Public Health* 15(7), 1557. <https://doi.org/10.3390/ijerph15071557>.
- World Health Organization (2020). *INTOX tools for harmonized data collection: Poisoning severity score. Appendix 1 in Poisons Centre Training Manual*. Geneva. <https://apps.who.int/iris/bitstream/handle/10665/329502/WHO-FWC-PHE-EPE-13.01-eng.pdf?ua=1>.
- World Resources Institute (2013). Eutrophication and hypoxia map data set. <https://www.wri.org/resources/data-sets/eutrophication-hypoxia-map-data-set>. Accessed 21 January 2021.
- World Trade Organization (2021). Understanding the WTO: The agreements. [https://www.wto.org/english/thewto\\_e/whatis\\_e/tif\\_e/agrm1\\_e.htm](https://www.wto.org/english/thewto_e/whatis_e/tif_e/agrm1_e.htm). Accessed 10 January 2022.
- Wu, Y., Gu, B., Erisman, J.W., Reis, S., Fang, Y., Lu, X. and Zhang, X. (2016). PM2.5 pollution is substantially affected by ammonia emissions in China. *Environmental Pollution* 218, 86-94. <https://doi.org/10.1016/j.envpol.2016.08.027>.
- Yu, G., Wang, J., Liu, L., Li, Y., Zhang, Y. and Wang, S. (2020). The analysis of groundwater nitrate pollution and health risk assessment in rural areas of Yantai, China. *BMC Public Health* 20, 437. <https://doi.org/10.1186/s12889-020-08583-y>.

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