Agricultural Pollution
Pesticides

WORLD BANK GROUP

Figure 1: Spraying Rice Fields in Vietnam

Source: International Rice Research Institute (IRRI).

Figure 2: Fumigation of Banana Plantations with Fungicides in the Philippines

Source: Gert Kema, CCBY.

Why Care about Pesticide Pollution?

Agriculture's heavy and growing dependence on pesticides across large parts of the world, though partly fueled by pesticides' own effectiveness, is placing an ever-rising burden on human health, biodiversity, and even the agro-food sector. Pesticides are central to the mix of Green Revolution technologies that, by enabling agricultural intensification, have boosted agricultural productivity and output since the Second World War. When used correctly, pesticides are a labor-saving technology that can contain pest populations and improve crop yields, quality, and storability, at least in the short run. Outside the Middle East and North Africa where pesticide sales have generally stagnated, pesticide use has continued to rise across every region, generally benefitting food availability and aiding agricultural growth. Their uptake, however—and in many cases their misuse—has generally unleashed a cocktail of harmful chemicals into the environment, contaminating food and drinking water, and poisoning humans and wildlife alike. Pesticide poisonings may kill hundreds of thousands of people each year, including tens of thousands of farm workers, and millions more suffer health problems linked to exposure—with the vast majority occurring in developing countries (see impacts section below). Some 10 million species, or 99 percent of the earth's wild biodiversity, are in a precarious condition, and while habitat destruction is the leading cause, pesticide pollution is also considered a major contributor. Looking forward moreover, the influence of climate change on pest dynamics, along with rising food demand and the ongoing shift to intensive farming in the developing world, could make this situation worse.

Nature and Magnitude of the Problem

Globally, approximately 2.7 million tons of pesticides were reportedly applied to agricultural land in 2015—nearly 30 percent less than the peak of 3.8 million tons applied in 2012 (see Figure 3 based on Food and Agriculture Organization [FAO] data). Consumption is highest in China and the United States, which used somewhat less than 1.8 million and 0.5 million tons per year, respectively, and next highest in France, Brazil, and Japan. In relative terms, Costa Rica, Colombia, Israel, Chile, and China are among the most intensive users of these chemicals (among large players). Farmers in these countries apply an average of over 15 kg per hectare, versus 2–3 kg per hectare in France and the United States, and 0.2 kg per hectare in India and Mozambique. In certain countries, pesticide use has risen dramatically, in step with rapid agricultural growth. Vietnam, for example, went from consuming 14,000 tons of pesticides bearing 837 different trade names in 1990, to 50,000 tons bearing over 3,000 trade names in 2008. Pesticide imports by 11 Southeast Asian countries grew nearly sevenfold in value between 1990 and 2010.

Overall levels of pesticide use, meanwhile, are only one facet of the problem. The effects of pesticides—from

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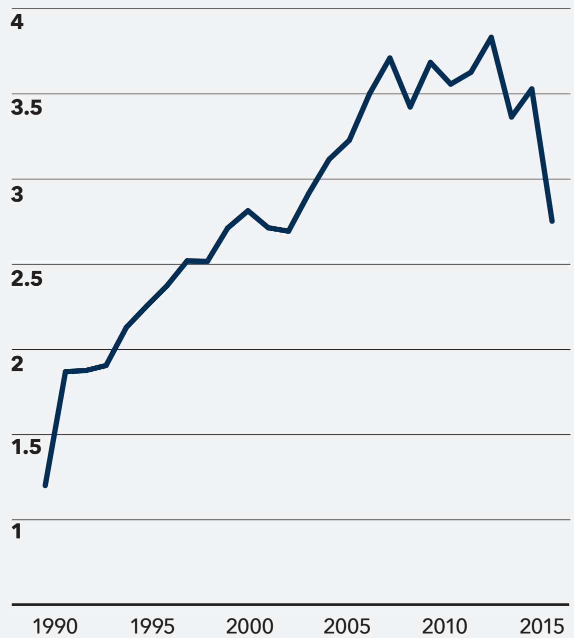
Box 1. What Are Pesticides?

A pesticide is any active substance or mixture thereof used to suppress unwanted organisms, or pests, including weeds, insects, fungi, bacteria, and rodents. In agriculture, which accounts for approximately 85 percent of all pesticide us e, pesticides are used before or after harvest to protect and preserve plants or plant products, to influence their growth, or destroy unwanted parts of these. They are also used to suppress pests in confined animal operations. They come in liquid and solid form: as concentrates, solutions, aerosols, and gas; and as dusts, granules, and powders. Pesticides are generally categorized on the basis of the type of pest they are primarily designed to target, the main types of pesticides in worldwide use being herbicides (40 percent), insecticides (33 percent), and fungicides (10 percent). Notwithstanding these simple categories, a great many pesticides are in use and most commercial pesticides have complex formulations containing active and inactive ingredients which range in purpose, toxicity, and persistence in the environment. According to the World Health Organization's 2009 system of classification, the active ingredients in pesticides range from "extremely or highly hazardous" (classes Ia and Ib) to "moderately hazardous" (class II), "slightly hazardous" (class III), or being "unlikely to present acute hazard in normal use."

Figure 3. Global Pesticide Use 1990–2015

Millions of tons of active ingredients



Source: Based on FAOSTAT data.

chronic to acute—depend not only on how heavily they are applied, but also on their toxicity and persistence in the environment, their handling, and the susceptibility of non-target organisms that get sprayed, ingest pesticide granules, or consume contaminated water or food.

Improper mixing, dosing, or timing, for instance, can render pesticides less effective and accelerate pest resistance, leading farmers to apply more. In Vietnam, where overuse has been an issue, it now takes pesticide doses 500 times greater than in the past to kill rice-feeding planthoppers. In Australia, wheat farmers' repeated application of overly diluted pesticides contributed to pernicious weed infestations in the 1980s and 1990s by accelerating herbicide resistance.

Even with proper use, battling pests with chemicals can lead to a kind of arms race that cyclically sends farmers reaching for more potent substances. Some users of herbicide-resistant and pesticidal genetically modified organisms (GMOs), for instance, are confronting pest resistance and reverting to the harsher chemicals that biotechnology had allowed them to replace (for example, potent, broad spectrum insecticides, and less benign herbicides).

Unsafe handling conditions also make contamination more likely, as when producers apply pesticides with a lack of protective gear, dispose of pesticide-laden equipment and containers carelessly, or expose entire communities through aerial fumigation—whether the cause is a lack of awareness, the desire to cut costs, or a lack of means.

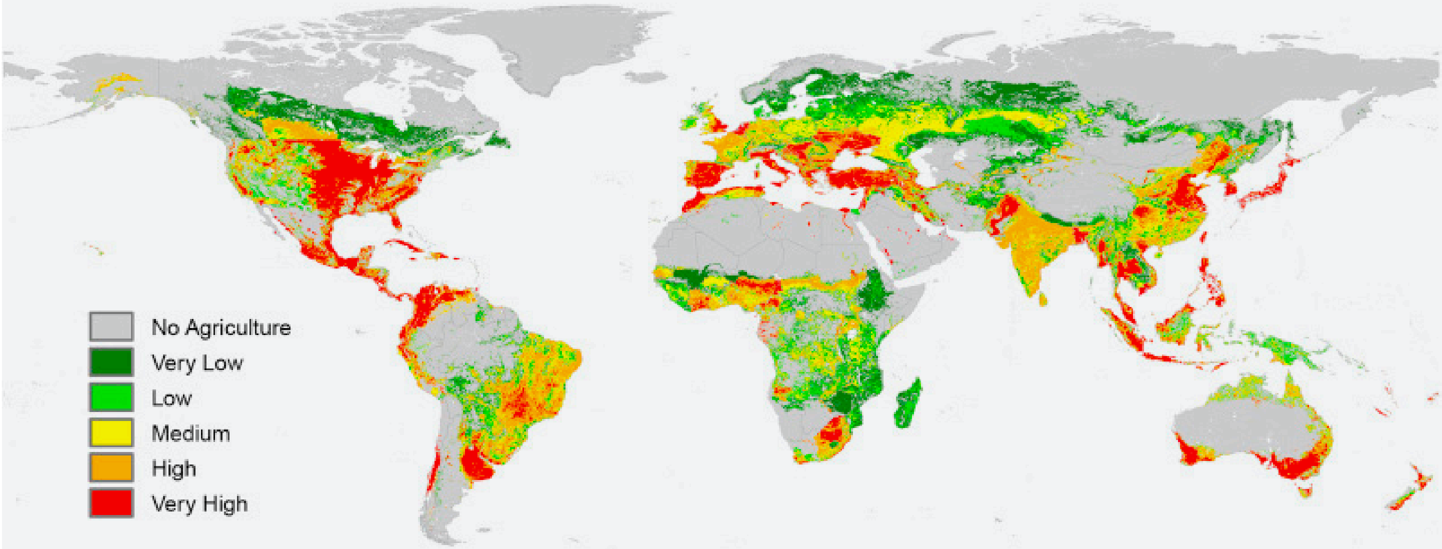
The use of highly toxic or persistent chemicals, including ones that have been banned in their country of origin or use, is another critical problem in many parts of the world; and the consequences of such chemicals can last long after their use has been uprooted. Continued use of these substances is often linked to poor monitoring and enforcement and other factors such as the availability and effectiveness of these chemicals, and vested economic interests in producing or selling off stocks of these pesticides. Another issue, particularly in developing countries, is the use of generic versions of pesticides in which the initial brand name producer has lost commercial interest, as these can be subject to inadequate toxicological monitoring. Generics represent around 30 percent of pesticide sales.

Impacts

Pesticides are now widespread in the environment, and notwithstanding their different toxicity, dispersal, and persistence properties, many of the pesticides that are released are harmful to non-target organisms, from mammals to invertebrates. More than 90 percent of water and fish samples from all streams sampled in the U.S. contain at least one pesticide, for example. Globally, modeling has shown that agricultural insecticides may be entering surface waters in over 40 percent of land area (see figure 4).

Particularly harmful is the presence of those persistent and accumulative pesticides that in some cases become more toxic in the environment because their

Figure 4. Global Risk of Freshwater Pollution from Agricultural Insecticide Application



Source: Ippolito et al. 2015. Permission required for reuse.

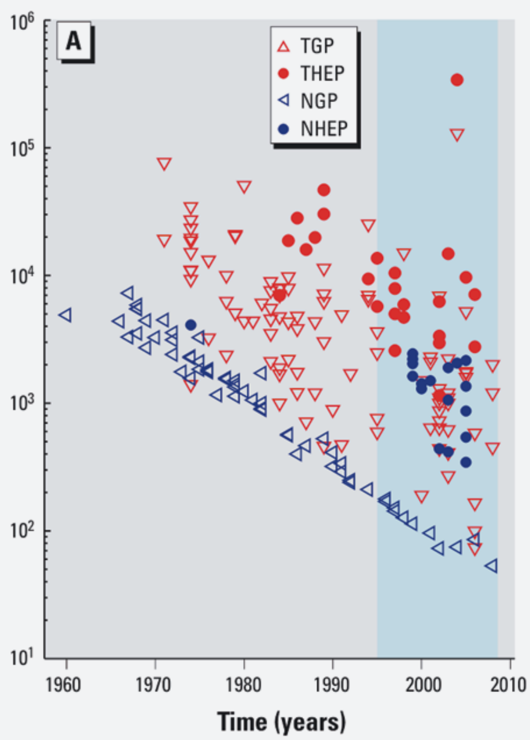
effects reach further into time and space (though persistent pesticides have sometimes been replaced by ones that are more acutely toxic). Examples of these so-called persistent organic pollutants (POPs) or persistent bioaccumulative and toxic (PBT) agents include substances such as dichlorodiphenyltrichloroethane (DDT), aldrin, endosulfans, and other organochlorine insecticides that have been banned or restricted in certain countries but are still in use in many. Figure 5 shows that while the levels of DDT detected in human tissue have declined globally over the past decades, they have remained substantially higher in tropical countries.

The most acute effects of pesticides can be seen in the many cases of pesticide poisoning that occur every year, particularly among agricultural workers and in developing countries. Reliable global estimates of the number of cases of pesticide poisoning are lacking—a reflection of data inadequacies and aggregation challenges. In the mid-1980s, the WHO found that there were probably over 1 million cases (and possibly more than 2 million cases) of acute, unintentional poisoning with severe manifestations each year—70 percent attributed to occupational exposure, and hundreds of thousands of related deaths (WHO 1990). The same report calculated that, based on the estimate that 1 percent of all pesticide users could be poisoned each year in China, there could be 2.5–5 million cases of unintentional poisonings there each year (WHO 1990). In developed countries, where the incidence of acute pesticide poisoning is known to be much lower than it is in developing countries, more than 18 per 100,000 full-time workers and 7.4 million school children may be affected according to more recent studies (Thundiyil et al. 2008).

Pesticide-related poisonings and deaths, meanwhile,

Figure 5. DDT Levels in Humans 1960–2008

Nanograms per gram of lipid weight



Source: Ritter et al. 2011, in UNEP 2012 (GEO5). Permission required for reuse.
Note: Whereas exposure in the general population reflects exposure to agricultural uses of DDT, mostly in the past, the "highly exposed" populations were primarily affected by indoor spraying in the context of malaria control.

Figure 6. Hand Pollinating Pear Orchards in Sichuan, China

Source: © Eric Tourneret.

Figure 7. Applying Pesticide to Crops in Yunnan, China

Source: © Mads Nissen / Panos.

are widespread among fish, birds, and other forms of wildlife, often in connection with the use of organophosphates and carbamates in insecticides. Invertebrates, including beneficial insects such as natural predators and pollinators, suffer the most severely from pesticides, as they are often most closely related to target organisms. Pesticides such as neonicotinoids, for instance, have been shown to impair bees' ability to navigate, implicating these in colony collapse crises. Pesticides can also kill beneficial soil microbes, including nitrogen-fixing ones, leading to higher fertilizer requirements and increasing plants' susceptibility to disease.

Though less visible and understood, the worst effects of pesticide pollution on living organisms may be connected to its chronic effects on growth, physiology, reproduction, and behavior. Certain pesticides, for example, mimic hormones in humans and wildlife, leading to endocrine disruption, afflictions of the reproductive system, and certain forms of cancer. Prenatal and early life exposure to certain organophosphates still used in agriculture (for example, chlorpyrifos) may also hamper brain development in children. As already noted above, another problem that can develop over time as pesticides are used repeatedly in a given environment is that of pest resistance. Some 42 percent of the species on the threatened or endangered species lists in the United States are at risk primarily because of alien-invasive species that have proliferated in part because of pesticide overuse (Pimentel, Zuniga, and Morrison 2005).

Several of these and other impacts cause direct economic losses to the agro-food sector. The loss of pollination services in certain parts of China—which some attribute to the heavy use of pesticides—, for example, has left no choice but to hand-pollinate fruit trees, a labor-intensive activity valued at tens of billions of dollars worldwide (see Figure 6). In addition to being costly, occupational hazards make it harder for the farm sector to compete for increasingly scarce labor. Whether related to soil fertility, worker safety, pest resistance, plant pathology, or fish stocks, the various productivity impacts of pesticide use directly harm farm profitability. In addition, pesticide-related food safety concerns, verified or perceived, mean lost market opportunities. In 2015, mere rumors of pesticides being discovered on strawberries in Beijing led local producers to lose millions of yuan within weeks before public authorities could carry out tests that assuaged consumer fears. Meanwhile, the failure to meet pesticide residue screening requirements costs developing country exporters large sums in rejected products and foregone trade. Pesticide pollution is also problematic well beyond the agro-food sector. Pesticide contamination of both surface water and groundwater is of particular concern given reliance on these for drinking water.

Drivers

The drivers of excessive and improper pesticide use are as varied as the problems associated with the use of these chemicals. These range from classic externality, information, principal-agent, and coordination failures, to behavioral, physical, and structural path dependencies.

Agricultural producers do not generally face the full social and environmental costs of excessive and improper (or even illegal) pesticide use, and do not always fully perceive the private costs they do face in terms of pest resistance or chronic health effects. On the input side of the market, meanwhile, this mixture of externalities, information asymmetries, and weak regulatory enforcement can translate into a strong profit motive for pesticide suppliers to market chemicals for which there are buyers, irrespective of bans or adverse downstream consequences. Marketing and extension efforts, as well as subsidies in certain contexts, help to boost pesticide purchases by touting their benefits, offering discounts for bulk or bundled input purchases, or simply lowering their price.

Yet pesticide misuse often persists despite the heft and salience of certain risks to producers, such as the loss of income linked with market rejection, or the loss of good health or life due to pesticide poisoning. Even when producers are aware of such overwhelming private costs, they can lack the technical or financial means, or knowledge, to take corrective action. Behavioral factors (for example, action-intention divides and social norms), coordination failures (when gains from change cannot be achieved by acting alone), and principal-agent problems (when workers making decisions face lesser consequences than their employers) can intervene, as can various input market issues that ultimately limit producers' options with regard to what chemicals they apply and how.

In highly commercial farming contexts however—as in industrial production systems—the persistence of highly polluting practices (that is, associated with negative externalities) has often less to do with resource, information, institutional, or cognitive constraints, as it has to do with path dependence, and possibly the power to influence regulation. If pesticide dependence is particularly pronounced in highly specialized production systems that intensively grow a single or small number of species, this is partly due to the tendency for these simplified agroecosystems to have fewer natural defenses against pests (for example, in field crop, fruit, and beverage tree monocultures). Their options are structurally constrained, to the extent that switching to less chemical-dependent modes of production can be cost-prohibitive. While industrial farms have greater means to adjust their practices to maximize profit and comply with regulatory standards, they also have more means to shape regulators' attempts to correct for externalities for their commercial benefit. Meanwhile, certain wholesalers, retailers, and consumers play a role by demanding perfectly unblemished products, strengthening the incentive for farms to use pesticides.

What Can Be Done?

Though some of the costs of pesticide pollution are what are known as externalities in that they affect a diffuse set of actors, farmers stand to benefit privately and substantially, in many cases, from investing in better management practices and technologies. Preventive pest control can often save farmers more time and money, over time, than can the systematic use of pesticides with all the risks this brings. For example, integrated pest management (IPM), an approach to pest control which favors natural pest control mechanisms and rests on synthetic pesticides only as a last resort, is less aggressive than other methods, to be sure, but can ultimately be less costly. The following are some of the approaches that can be used to address pesticide pollution preventively.

Information, awareness, norm change, and technology. For farmers to use pesticides more judiciously, it can help for them to be aware of the near- and long-term benefits of alternative choices, as well as to have material and financial access to these. This requires data and research to, for example, develop early warning capacity and effective control techniques. Technical changes in how pesticides are formulated or applied—ranging from the simple to the sophisticated—can significantly reduce the use of and exposure to toxic pesticide substances. The use of pesticide-coated seed, for instance, can help reduce pesticide contact and applications when used correctly, while biocontrols (e.g., the inoculation of soil with non-toxigenic fungi that outcompete unwanted toxic ones) can sometimes offer more benign alternatives to harsh chemicals (though they too can carry risks).

To the extent that current practices can be held in place by social expectations—for instance to maintain the appearance of a clean field—changes in practices may also require social norm change. Vietnam in the 2000s met considerable success in gaining control over pesticide abuse and planthopper devastation in the Mekong Delta, its rice basket region, by marketing IPM through posters, leaflets, television spots, and a radio soap opera (it later initiated regulatory measures to prevent exaggerated pesticide marketing claims). In experimental fields, farmer incomes improved by 8–10 percent, and in 2006, the campaign was aided by the demonstration effect of an outbreak disproportionately harming heavier users of pesticides.

Market incentives and the removal of subsidies. These can also help enhance the profitability, or shorten the payback period, of changing practices. In some contexts, this requires the removal of direct or indirect subsidies. In 1986, for example, Indonesia stopped subsidizing a range of pesticides in an attempt to get a handle on their rampant use—a measure that was effective until the market was flooded by lower cost, generic versions of these in the 2000s. In the United States, a voluntary, organic certification standard developed by the Department of Agriculture in 2000 has allowed a growing (though still marginal) share of consumers to pay a motivating price premium to farmers for avoiding most synthetic inputs including pesticides. In this respect, heightened awareness and norm change among the public and further down food value chains can also yield results. Lowering retailer and consumer expectations when it comes to the aesthetic perfection of the produce they buy can weaken farmers' incentive to deliver unblemished products at all cost.

Bans, standards, enforcement, and monitoring. Where chemical bans or restrictions and food safety or other standards can be implemented effectively and transparently, these can contribute to informing, raising awareness, diffusing technology, and if they are tied to market access, economically incentivizing farmers to use pesticides more carefully. Legal access to the European Union, North American, and other markets, for instance, is conditional on meeting maximum residue limits (MRLs) for food and feed, compliance with which, though not flawless, is monitored upon entry and within food distribution channels. With effective implementation, the results of pesticide bans can be clear and substantial. Bird deaths related to acute pesticide poisoning, for example, are thought to have declined from 67 million to (a still substantial) 15 million between 1992 and 2012 in the United States, largely as a result of the elimination of certain organophosphates from agricultural use. Overall, pesticides are widely and heavily regulated substances as their production, use, sale, disposal, and presence are governed by both international and national texts in most countries. Monitoring and implementation remain a global challenge, however, as does the stringency of existing laws and regulations in certain cases, particularly as pesticide formulations and scientific evidence on their risks are constantly evolving.

Box 2. International Efforts to Address Pesticide Risks

While most pesticides are regulated at the national level, various international efforts have attempted to coordinate their oversight and raise awareness of their risks. Chief among these are the following.

- To promote the voluntary exchange of information, the FAO launched the **International Code of Conduct on the Distribution and Use of Pesticides** in 1985, and the United Nations Environment Programme (UNEP) set up the **London Guidelines for the Exchange of Information on Chemicals in International Trade** in 1987. In 1989, the FAO and UNEP jointly introduced the **Prior Informed Consent (PIC)** procedure to ensure that governments have adequate information to assess risks associated with chemical imports.
- Legally binding obligations have since replaced these according to the 1998 **Rotterdam Convention on Prior Informed Consent Procedure for Certain Hazardous Chemicals in International Trade**, which entered into force in 2004. Its aim is "to promote shared responsibility and cooperative efforts among parties in the international trade of certain hazardous chemicals [including pesticides] in order to protect human health and the environment from potential harm; and to contribute to the environmentally sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to parties."
- Also in force since 2004 is the 2001 **Stockholm Convention on Persistent Organic Pollutants**, which aims to protect human health and the environment by reducing or eliminating POP releases to the environment. The Convention recognizes 23 of these as of 2015, and requires parties to the Convention to, among other things, prohibit and eliminate, restrict, or reduce the use, production, import and export of those listed in annexes A, B and C respectively. In addition, the Convention has supported developing countries to properly dispose of stockpiles of obsolete POP pesticides. Other provisions relate namely to the safe management of POP wastes, research, education, information exchange, and data collection.
- The 1980 **Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal** aims to protect human health and the environment from the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes, including that of POPs. Since its entry into force in 1992, shipments of hazardous and other wastes that are made without consent have been illegal in application of the PIC procedure. The Convention also obliges parties to ensure that hazardous and other wastes are managed and disposed of in an environmentally sound manner.
- **The Codex Alimentarius**—the UN's international food standards, guidelines, and codes of practice, established jointly by the FAO and the WHO in 1963—sets MRLs for pesticides found in food, to protect health and ensure a level playing field for trade among participating countries.
- The **World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures** requires that pesticide standards be based upon "an assessment, as appropriate to the circumstances, of the risks to human, animal or plant life or health" and encourages compliance with the UN Codex Alimentarius. Negotiated under the 1986–1994 Uruguay Round of trade negotiations, the SPS agreement entered into force in 1995.
- The **WHO's Recommended Classification of Pesticides by Hazard**, published (most recently in 2009) by its International Program on Chemical Safety (IPCS), provides a scientifically consensual and widely used description of the risks associated with chemical exposures, aligned with the UN's Globally Harmonized System of Classification and Labelling of Chemicals (GHS, first adopted in 2003). The IPCS develops training modules on chemical safety in an attempt to harmonize approaches to risk assessment. The WHO's International Agency for Research on Cancer (IARC) reviews evidence on the carcinogenicity of chemical agents; and the WHO Pesticide Evaluation Scheme (WHOPES) provides information on pesticides and public health to facilitate pesticide registration within member countries.