Pesticides and Sustainability

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In her 1962 book *Silent Spring*, Rachel Carson presented a powerful picture of the threat of pesticides to sustainability (Carson, 1962). The unchecked use of pesticides, she documented, harmed people and ecosystems, poisoned the Earth, and threatened to sever the "web of life" upon which all living beings depend. *Silent Spring* led to significant awareness and outcry against the indiscriminate use of pesticides and helped spark contemporary movements for sustainability and environmental protection. Despite increasing awareness of the threat pesticides present to sustainability and health, however, the global use of commercial pesticides has more than *tripled* in the six decades since the publication of *Silent Spring* (Food and Agriculture Organization of the United Nations [FAO], 2021a). In fact, the increased production and use of pesticides has outpaced the growth of other anthropogenic drivers of global environmental change (such as carbon emissions) over the past half-century (Bernhardt et al., 2017). This high level of global pesticide usage has been maintained despite the widespread knowledge of the threats that pesticides can pose to ecosystems, sustainability, and human health. What has led to the dramatic increase in chemical substances intended to kill? What are the implications for the health and well-being of people and other living beings? And what routes might there be toward more sustainable cultivation of food? To answer these questions, it's necessary to look at the ways synthetic pesticides have been part of a broader transformation of farming.

A Growing Problem

Pesticides are any substance used to kill or alter the behavior of any organism considered a pest, including plants, insects, vertebrates, and fungi. Although nonsynthetic substances (nicotine from the tobacco plant and pyrethrum from chrysanthemum flowers, for example) can be used as pesticides, global pesticide use is dominated by industrially produced synthetic chemicals. Globally, over *eight billion pounds* of synthetic pesticides are used every year, primarily in agriculture (FAO, 2021b). The early growth of the pesticide industry was driven by the search for ways to commercialize toxic industrial wastes. Arsenic, a toxic byproduct of copper smelting, found its way to fields in the late 1800s as a commercial insecticide, and arsenical insecticides drove the early growth of the pesticide industry, providing a means for companies to turn toxic waste into a profitable commodity (Romero, 2021). Arsenical insecticides were soon joined by compounds first developed as weapons of chemical warfare, in addition to synthetic, petroleum-based pesticides, which are an often-overlooked part of industrial agriculture's dependence on petrochemicals (Demeneix, 2020); Russell, 2001). But what accounts for industrial agriculture's chemical dependency?

A Dow Chemical pesticide plant is shown from a park overlook on April 12, 2007, in Midland, Michigan.

Photo courtesy Bill Pugliano, Getty Images.

One way to understand the rise of pesticides in agriculture is through the concept of *appropriationism*. Farmers can benefit from and work to foster ecological and biological processes without having to purchase anything: saving seeds, for example, to grow new plants and recycling nutrients on the farm to maintain soil fertility. In the process of *appropriation*, capitalist firms have marketed commercial inputs like patented seeds and synthetic fertilizers to replace or supplement natural biophysical processes and labor-intensive practices (Goodman et al., 1987). For example, in the twentieth century, researchers and companies developed and promoted hybrid and patented seeds that led to an increasing dependency by farmers on agro-industrial firms and a genetic simplification of agriculture (Kloppenberg, 2004). Pesticides and other commercial inputs may offer benefits to farmers by reducing labor requirements or increasing productivity. However, pesticides often replace more ecologically complex and interdependent agricultural systems and practices, which can provide ecological checks against pests. As farmers have shifted toward market-based inputs, agriculture as a whole has become increasingly *monocultural*. Monocultures, or agricultural systems dominated by a single crop, are far more vulnerable to pests, and pesticides further contribute to ecological simplification and standardization by destroying "unwanted" (and other) organisms (Uekötter, 2014).

In the twentieth century, pesticides were central to far-reaching changes to agriculture and food systems and the global expansion of monocultures. Following World War II, the US government and nonprofit organizations increasingly supported a path to global agricultural development through productivity-boosting agricultural technologies. This "Green Revolution," proponents believed, would dramatically increase yields and combat hunger while countering communism and movements for land redistribution in the Global South (Cullather, 2010). Hunger, from this perspective, was not a consequence of inequality. Instead, hunger was treated as a technological problem that could be solved through new plant varieties, fertilizers, and pesticides. The Green Revolution did increase global agricultural production and through herbicides, reduced the amount of labor necessary to cultivate crops. It did so, however, through a dramatic increase in pesticides and the displacement of more ecologically complex and interdependent systems of food cultivation by petrochemical-dependent agriculture (Perfecto et al., 2019). This trajectory continues into the present day. In Brazil and Argentina, for example, an expanding frontier of soybean cultivation has contributed to tremendous habitat destruction and the displacement of diverse agricultural systems, and both countries are now ranked among the top five consumers of pesticides globally (FAO, 2021b; Rekow,

Agricultural technologies such as heavy machinery, fertilizers, and pesticides are a hallmark of the so-called Green Revolution.

Photo courtesy Pixabay.

2019). In China and India, pesticide usage has increased dramatically in recent years, and both countries are now also major producers of pesticides (Shattuck, 2021). In Africa, where pesticide usage has long remained much lower than in other regions, development and philanthropy organizations have been promoting a "New Green Revolution," and pesticide usage is skyrocketing (Stein & Luna, 2021; Vercillo et al., 2020).

As a consequence, many farmers around the world are now on what has been termed the *pesticide treadmill* (see Figure 1). The use of pesticides can lead to initial increases in production and profitability, promising greater profitability while requiring less work than manual pest-control methods. However, these profits can quickly disappear as increased production leads to declining prices for agricultural products (Cochrane, 1993; Luna, 2019). Meanwhile, species targeted as "pests" can evolve

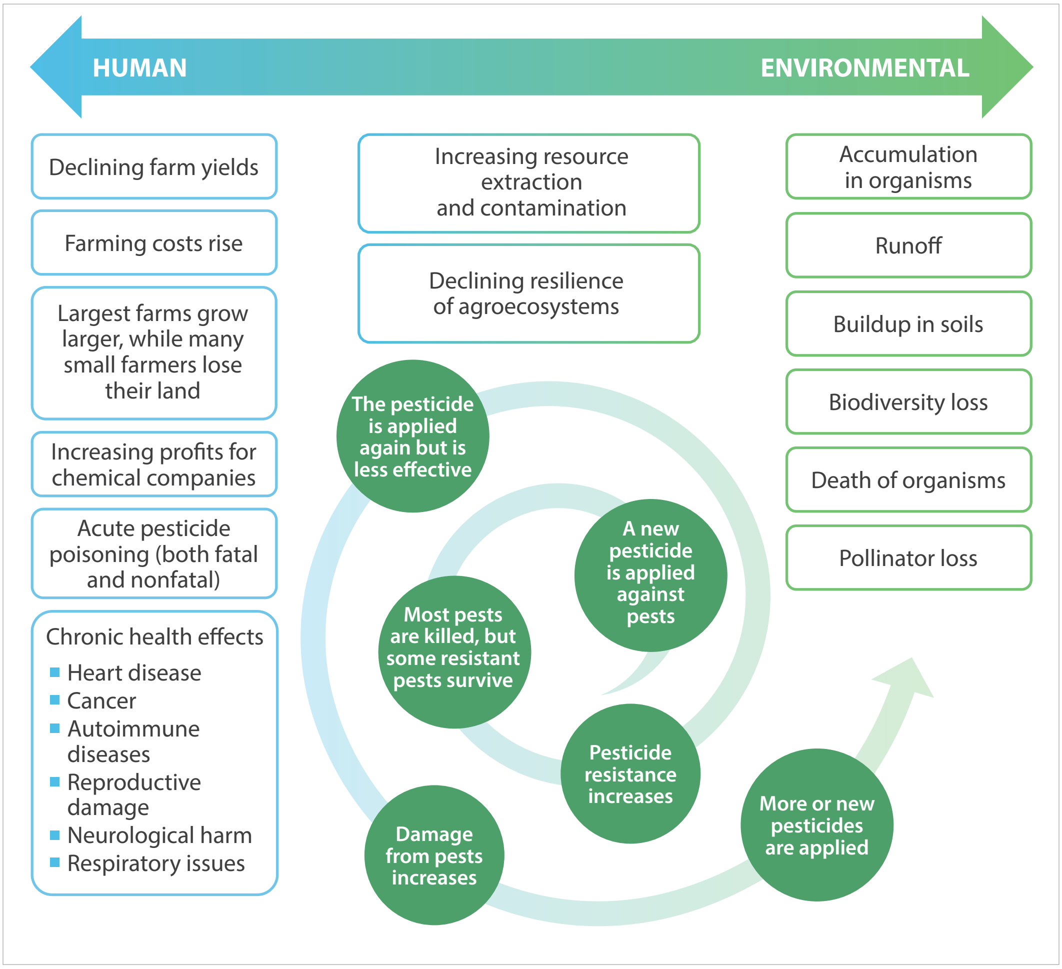

Figure 1: The pesticide treadmill and its consequences.

Adapted from Cochrane (1993), Duncan (1996), and Luna (2019).

resistance to chemicals over multiple generations, and these resistant species can spread even more quickly when other species that prey upon or compete with them are destroyed by pesticides (Lundgren & Fausti, 2015). Within the paradigm of pesticide-intensive agriculture, the solution to the problem of pest resistance is *even more* chemicals or the development of new chemicals—further accelerating the treadmill (Guthman, 2019, Werner et al., 2021). As a result of these shifts in farming, millions of square miles of land are now a destination for chemicals designed to kill, and the global pesticide industry, dominated by a handful of massive transnational companies such as Syngenta, BASF, Bayer, and Dow, represents over $50 billion in sales per year (Shattuck, 2021).

Pesticides, People, and the Environment

Agrarian landscapes and global ecologies have been profoundly altered by the intentional proliferation of toxic pesticides. The implications for sustainability are immense, with far-reaching impacts on human health, biodiversity, resource consumption, and environmental pollution. The toxic properties of pesticides, so central to their commercial value and use, pose a grave threat to sustainability. Many pesticides that were once widely used, such as DDT and aldrin, are now banned because of their harmful effects on people and the environment. The majority of chemicals internationally prohibited by the Stockholm Convention on Persistent Organic Pollutants, in fact, are pesticides, and some still persist widely in the environment and continue to accumulate in organisms and food webs (United Nations Environmental Programme, 2020; see Figure 2). Many pesticides that are currently in widespread use, moreover, are hazardous to both human health and the environment, and many formally banned pesticides are still widely used in the Global South (Fuhrimann et al., 2022; Sharma et al., 2020; Stein & Luna, 2021; World Health Organization [WHO], 2019).

Pesticides pose myriad threats to human health, ranging from endocrine disruption (interference with hormones), respiratory issues, nervous system damage, neurotoxicity, skin diseases, organ failure, and carcinogenicity (Galt & Asprooth, 2021; Rani et al., 2021). Acute toxicity refers to the immediate toxicity of a chemical to organisms. Most organophosphate insecticides, which were first developed as nerve agents for chemical warfare, are acutely toxic and can immediately harm or even kill people upon exposure (Davis, 2014). Other pesticides, however, such as DDT and glyphosate, have low levels of acute toxicity to people but can cause harm over time, especially given prolonged or repeated exposure. Globally, an estimated 11,000 people every year are killed by accidental acute pesticide poisoning, and an additional 385 *million* are poisoned (Boedeker et al., 2020). These acute poisonings can also lead to long-term illness and death. Many chemicals, moreover, have both acute (short-term) and chronic (long-term) effects. The health effects of pesticides can also be difficult to definitively isolate, contributing to a “toxic uncertainty” that favors a chemical-intensive status quo. Because the dimensions of exposure and harm are often quite uncertain, the monitoring of pesticide usage is often incomplete, people are frequently exposed to multiple chemicals, and the relationship between exposure and illness can be difficult to trace with certainty (Shattuck, 2020).

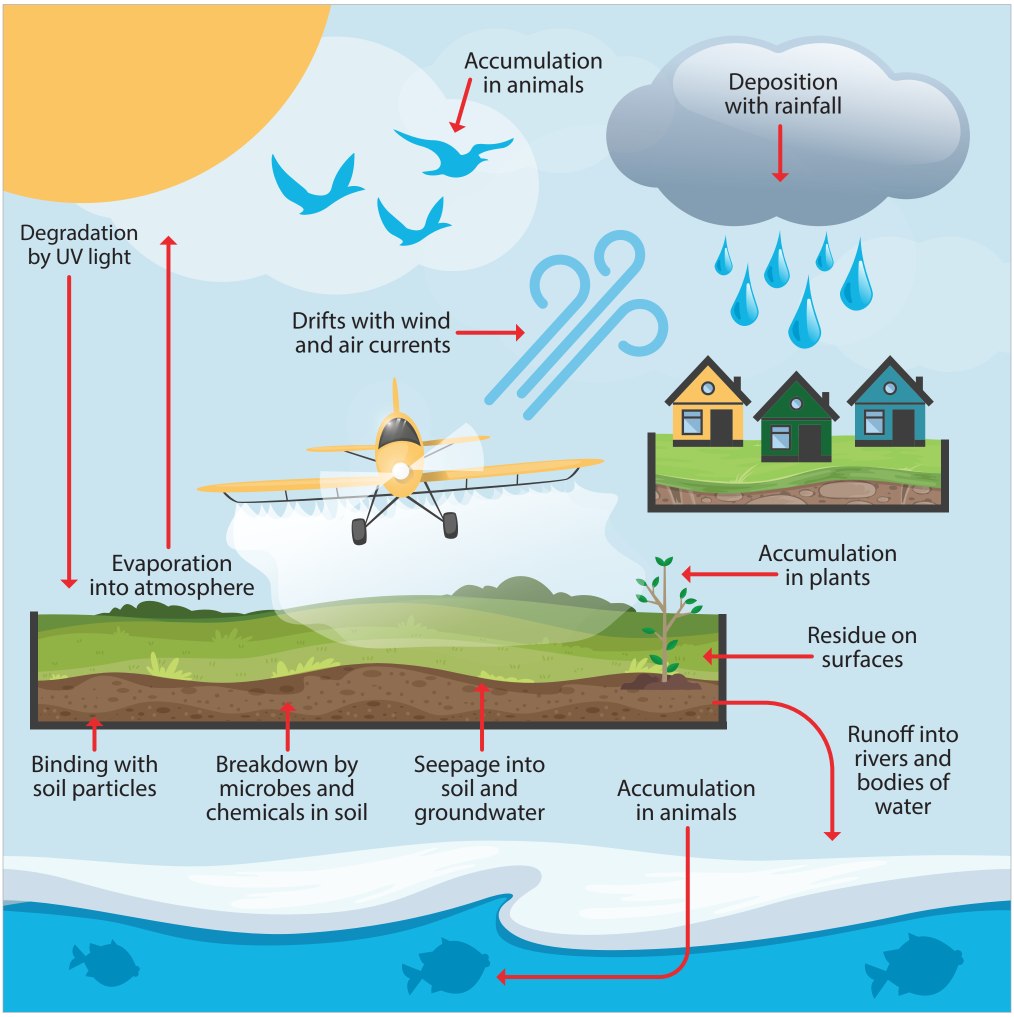

Figure 2: Pesticides in the environment.

Adapted from Gavrilescu (2005) and Kamrin (1997).

Although the overall harm of pesticides on people and the environment is immense, these effects are profoundly unequal. Most often, the people most indispensable to agricultural production are also most vulnerable to the harmful effects of pesticides. For farmworkers working in chemical-intensive agriculture, the risk of exposure is quite high (Saxton, 2021). This toxic risk is intensified by other factors, including the exclusion of migrant workers from labor protections and citizenship rights and racism against agricultural workers (Svensson et al., 2013; Williams, 2021; Xiuhtecutli & Shattuck, 2021). And with small farmers and rural communities facing land dispossession and pressures from corporate agriculture, suicides by intentional pesticide poisoning have accounted for approximately fifteen million deaths, overwhelmingly in the Global South, since 1965 (Karunarathne et al., 2020).

Globally, the uneven harms of pesticides on people also intersect with harm to the environments and species upon which people depend.

Although the mode of action of some pesticides (the chemical and biophysical ways they are intended to work) is targeted at a limited range of species, virtually all pesticides are potentially harmful to species other than those targeted as "pests." Even the very definition of "pest" is subject to interpretation. For example, plants targeted as "weeds" by industrial agriculture can have a wide variety of important benefits to ecosystems and can even serve as food (Argüelles & March, 2021). In addition, chemicals frequently move beyond fields and other places where they are used, traveling with the wind, washing into bodies of water through runoff, and accumulating in organisms far beyond the site of application (see Figure 2). Extensive use of pesticides also leads to accumulation in soils and contributes (both intentionally and unintentionally) to the destruction of fungi, bacteria, worms, and other organisms that are important to soil health (Crews et al., 2018). Taken as a whole, pesticides that are widely used today pose a major threat to biodiversity (Geiger et al., 2010). Because many of the organisms that are threatened by pesticides are also ecologically critical to human nutrition (pollinators and edible wild plants, for example), pesticides ostensibly deployed to increase food production can, in fact, *undermine* food security (Chagnon et al., 2015; Duflot et al., 2022).

Cultivating Sustainability

The widespread use of pesticides represents a clear (and unequal) threat to sustainability on a global scale. Although many advocates argue that the extensive usage of pesticides is necessary to feed the world, agricultural *overproduction* is currently a major problem in the corporate food system, even as many people starve or go hungry because of unequal access to food (Holt-Gimenez, 2019; Pereira et al., 2020). The argument that chemicals are necessary to prevent hunger can serve to deflect from these problems, instead presenting a technological solution that ultimately undermines the very resources necessary for long-term agricultural sustainability. The problems associated with pesticides are immense and far-reaching, and much of the global system of food and agriculture is dependent on chemicals. Similarly, there is a wide variety of possible responses to the harms associated with pesticides, ranging from individual consumptive decisions to more far-reaching challenges to the dominant model of chemical-intensive agricultural production (MacKendrick, 2018). Although these responses may not be mutually exclusive and vary substantially according to geographical context, they offer different understandings of how sustainability can be achieved and what the future of food and agriculture might look like.

The organic certification seal of the United States Department of Agriculture (USDA). Public Domain via Wikimedia Commons.

Many affluent and middle-class consumers, especially in the United States and Europe, often focus on purchasing organic foods as a solution to the dangers presented by pesticides. Although organic requirements may vary by country, foods that carry an "organic" label are certified by a governmental or other certifying body to be produced without the use of synthetic pesticides. For many consumers, organic food may represent a promise of a more environmentally sustainable and healthy diet. However, an exclusive focus on the labeling and purchase of organic food has significant limitations as a sustainability solution. Farms with organic certification constitute only 1.4 percent of global agricultural land, although this percentage is growing (Willer & Lernoud, 2019). Absent other action, an exclusive focus on the need to "eat organic" leaves the broader problems of chemical-intensive agriculture intact and privileges consumers who can afford products that carry the "organic premium" associated with certification (Guthman, 2011; Luna et al., 2021). The majority of organic certification programs also fall short of more holistic and sustainable principles embraced by many advocates and practitioners of organic farming (Seufert et al., 2017).

Globally, international agreements—most importantly the Stockholm Convention and the Rotterdam Convention—have been important in reducing the use of some of the most hazardous pesticides (Núñez-Rocha & Martínez-Zarzoso, 2019). Most pesticide regulation, however, occurs at the national scale. The patchwork of rules meant to protect people and the environment from pesticides often places the burden of "safe use" on individuals applying chemicals. This approach fails to adequately prevent harm while leaving the power and profitability of the pesticide industry intact and prioritizing the well-being of consumers in the Global North (Galt, 2014; Shattuck, 2019). In many countries, moreover, pesticide regulation represents an endless game of catch-up, focusing only on reducing harms that have already been conclusively demonstrated. In contrast, many activists, scientists, and health professionals push for the "precautionary principle" in pesticide regulation. This principle stresses that when risks are poorly understood, *potential harms* should be addressed and prevented beforehand, rather than after the fact (Harrison, 2011).

Truly addressing the social and environmental crisis of the extensive and expanding pesticide usage also requires widespread changes to an agricultural system that is dependent on industrially produced toxins. The substitution of harmful synthetic pesticides with biopesticides or pest-resistant crops represents one potential means of reducing the overall environmental and human harms of agriculture (Kumar & Singh, 2015). However, an approach that merely replaces existing pesticides with pesticide-resistant plant varieties and biopesticides may not be effective in countering the crises of chemical-intensive agriculture. Initial pesticide reduction through the use of genetically modified plant varieties engineered to be toxic to pests, for instance, has been erased as insects have developed resistance to these toxins (Kranthi & Stone, 2020). Integrated pest management (IPM) is a more expansive approach to the reduction or elimination of synthetic pesticides. Instead of the *elimination* of pests, IPM focuses on *managing* pests using a combination of factors that seek to minimize ecological disruption (Stenberg, 2017). Despite its potential, however, IPM is often deployed as a complement to (rather than a fundamental challenge to) the dominant system of chemical-intensive agriculture, and the language of IPM has even been appropriated by the pesticide industry (Deguine et al., 2021).

More holistically, *agroecology* represents a range of approaches that emphasize ecological processes over nonrenewable inputs such as pesticides. Agroecological approaches understand agriculture as a complex and interdependent *agroecosystem*. Socially, agroecology stresses the importance of global cultural diversity, place-based knowledge systems, knowledge sharing, and grassroots approaches to agricultural production (Altieri, 2018). Agroecology emphasizes *agrobiodiversity* as an indispensable part of the global food system, sustained by millions of small farmers around the world. Related movements for *food sovereignty* assert both peoples' right to food and to community self-determination of food systems and agricultural practices (Montenegro de Wit, 2020). Although not all mobilizations for food sovereignty reject the usage of pesticides, the concept of food sovereignty directly challenges the imbalances of wealth, power, access, and decision-making in the global agri-food system that underpin the intensive use and unequal effects of pesticides (Food First Information and Action Network, 2020; Rosset & Martinez-Torrez, 2013).

From one perspective, agroecology and food sovereignty represent radical departures from the global paradigm of corporate consolidation and chemical-intensive agriculture. But remember that synthetic pesticides are a new, if profoundly destructive, newcomer to agriculture and to global environments. Although many small farmers' livelihoods are threatened by the expansion of pesticide-intensive monocultures, and an increasing number are adopting pesticides, smallholder producers still represent the *majority* of the world's farmers and produce half of the world's food on 30 percent of the world's agricultural land (Samberg et al., 2016). Many of these small farmers do not use chemicals, although their production practices may not be certified as "organic." Movements for agroecology and food sovereignty are reminders that there are alternative visions for a food system that fosters biodiversity rather than undermines global sustainability and that many of these visions are also in practice.

Conclusion

Pesticides are central to the petrochemical-dependent farming that dominates the global agri-food system. The current dynamics of synthetic pesticide production and use represent a monumental threat to biodiversity, to rural communities, and to the health of people and ecosystems on a global scale. Because the harms of pesticides are so complex and extensive, precautionary approaches to pesticide control and regulation are necessary. However, confronting the roots of *unsustainability* requires more than a change in the chemicals that are used. Moving away from the paradigm of chemical-intensive agriculture and the dynamics of environmental and social exploitation that underpin it requires approaches that prioritize health, nourishment, and environmental sustainability over corporate profits. The seeds for this change are already being sown. Despite a global agricultural system that commodifies both food and toxins, more biodiverse and sustainable ways of cultivating food are not only possible and necessary but already exist. Reducing and repairing the harms of synthetic pesticides on a global scale represents a monumental challenge, but one already being taken on by many farmers, workers, social movements, scientists, and rural communities around the world.

Bibliography

Altieri, M. A. (2018). *Agroecology: The science of sustainable agriculture* (2nd ed.). CRC Press. https://doi.org/10.1201/9780429495465

Argüelles, L., & March, H. (2021). Weeds in action: Vegetal political ecology of unwanted plants. *Progress in Human Geography, 46*(1), 44–66. Advance online publication. https://doi.org/10.1177/03091325211054966

Atwood, D., & Paisley-Jones, C. (2017). *Pesticides Industry sales and usage: 2008–2012 market estimates*. US Environmental Protection Agency. https://www.epa.gov/sites/default/files/2017-01/documents/pesticides-industry-sales-usage-2016_0.pdf

Bernhardt, E. S., Rosi, E. J., & Gessner, M. O. (2017). Synthetic chemicals as agents of global change. *Frontiers in Ecology and the Environment, 15*(2), 84–90. https://doi.org/10.1002/fee.1450

Boedeker, W., Watts, M., Clausing, P., & Marquez, E. (2020). The global distribution of acute unintentional pesticide poisoning: Estimations based on a systematic review. *BMC Public Health, 20*(1), 1875. Advance online publication. https://doi.org/10.1186/s12889-020-09939-0

Carson, R. (1962). *Silent spring*. Houghton Mifflin.

Chagnon, M., Kreutzweiser, D., Mitchell, E. A. D., Morrissey, C. A., Noome, D. A., & Van der Sluijs, J. P. (2015). Risks of large-scale use of systemic insecticides to ecosystem functioning and services. *Environmental Science and Pollution Research International, 22*(1), 119–134. https://doi.org/10.1007/s11356-014-3277-x

Cochrane, W. W. (1993). *The development of American agriculture: A historical analysis* (2nd ed.). University of Minnesota Press.

Crews, T. E., Carton, W., & Olsson, L. (2018). Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Global Sustainability, 1*, e11. Advance online publication. https://doi.org/10.1017/sus.2018.11

Cullather, N. (2010). *The hungry world: America's Cold War battle against poverty in Asia*. Harvard University Press. https://doi.org/10.4159/9780674058828

Davis, F. R. (2014). *Banned: A history of pesticides and the science of toxicology*. Yale University Press. https://doi.org/10.12987/yale/9780300205176.001.0001

Deguine, J.-P., Aubertot, J.-N., Flor, R. J., Lescourret, F., Wyckhuys, K. A. G., & Ratnadass, A. (2021). Integrated pest management: Good intentions, hard realities. A review. *Agronomy for Sustainable Development, 41*(3), 38. Advance online publication. https://doi.org/10.1007/s13593-021-00689-w

Demeneix, B. A. (2020). How fossil fuel-derived pesticides and plastics harm health, biodiversity, and the climate. *The Lancet. Diabetes & Endocrinology, 8*(6), 462–464. https://doi.org/10.1016/S2213-8587(20)30116-9

Duflot, R., San-Cristobal, M., Andrieu, E., Choisis, J.-P., Esquerré, D., Ladet, S., Ouin, A., Rivers-Moore, J., Sheeren, D., Sirami, C., Fauvel, M., & Vialatte, A. (2022). Farming intensity indirectly reduces crop yield through negative effects on agrobiodiversity and key ecological functions. *Agriculture, Ecosystems & Environment, 326*, 107810. Advance online publication. https://doi.org/10.1016/j.agee.2021.107810

Duncan, C. A. M. (1996). *The centrality of agriculture: Between humankind and the rest of nature*. McGill-Queen's University Press.

Food and Agriculture Organization of the United Nations. (2021a). *Pesticides Use*. https://www.fao.org/faostat/en/#data/RP

Food and Agriculture Organization of the United Nations. (2021b). *World food and agriculture: Statistical yearbook 2021*. https://www.fao.org/documents/card/en/c/cb4477en/

Food First Information and Action Network. (2020). Beyond land—Territory and food sovereignty. *Nyéléni Newsletter, 41*. https://nyeleni.org/DOWNLOADS/newsletters/Nyeleni_Newsletter_Num_41_EN.pdf

Fuhrimann, S., Wan, C., Blouzard, E., Veludo, A., Holtman, Z., Chetty-Mhlanga, S., Dalvie, M. A., Atuhaire, A., Kromhout, H., Röösli, M., & Rother, H.-A. (2021). Pesticide research on environmental and human exposure and risks in Sub-Saharan Africa: A systematic literature review. *International Journal of Environmental Research and Public Health, 19*(1), 259. https://doi.org/10.3390/ijerph19010259

Galt, R. E. (2014). *Food systems in an unequal world: Pesticides, vegetables, and agrarian capitalism in Costa Rica*. The University of Arizona Press. https://doi.org/10.2307/j.ctt180r3hc

Galt, R. E., & Asprooth, L. (2021). The effects of agrochemicals on humans. In H. S. James (Ed.), *Handbook on the human impact of agriculture* (pp. 297–329). Edward Elgar Publishing. https://doi.org/10.4337/9781839101748.00028

Gavrilescu, M. (2005). Fate of pesticides in the environment and its bioremediation. *Engineering in Life Sciences, 5*(6), 497–526. https://doi.org/10.1002/elsc.200520098

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L. W., Dennis, C., Palmer, C., Oñate, J. J., . . . Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology, 11*(2), 97–105. https://doi.org/10.1016/j.baae.2009.12.001

Goodman, D., Sorj, B., & Wilkinson, J. (1987). *From farming to biotechnology: A theory of agro-industrial development*. Basil Blackwell.

Guthman, J. (2011). *Weighing in: Obesity, food justice, and the limits of capitalism*. University of California Press.

Guthman, J. (2019). *Wilted: Pathogens, chemicals, and the fragile future of the strawberry industry*. University of California Press.

Harrison, J. L. (2011). *Pesticide drift and the pursuit of environmental justice*. MIT Press. https://doi.org/10.7551/mitpress/9780262015981.001.0001

Holt-Gimenez, E. (2019). *Can we feed the world without destroying it?* John Wiley & Sons.

Kamrin, M. A. (1997). *Pesticide profiles: Toxicity, environmental impact, and fate*. CRC Press.

Karunarathne, A., Gunnell, D., Konradsen, F., & Eddleston, M. (2020). How many premature deaths from pesticide suicide have occurred since the agricultural Green Revolution? *Clinical Toxicology (Philadelphia, PA), 58*(4), 227–232. https://doi.org/10.1080/15563650.2019.1662433

Kloppenburg, J. R. (2004). *First the seed the political economy of plant biotechnology, 1492–2000*. University of Wisconsin Press.

Kranthi, K. R., & Stone, G. D. (2020). Long-term impacts of Bt cotton in India. *Nature Plants, 6*(3), 188–196. https://doi.org/10.1038/s41477-020-0615-5

Kumar, S., & Singh, A. (2015). Biopesticides: Present status and the future prospects. *Journal of Fertilizers & Pesticides, 6*(2). Advance online publication. https://doi.org/10.4172/2471-2728.1000e129

Luna, J. K. (2019). "Pesticides are our children now": Cultural change and the technological treadmill in the Burkina Faso cotton sector. *Agriculture and Human Values, 37*, 449–462. https://doi.org/10.1007/s10460-019-09999-y

Luna, J. K., Chalit Hernandez, B., & Sawadogo, A. (2021). The paradoxes of purity in organic agriculture in Burkina Faso. *Geoforum, 127*, 46–56. https://doi.org/10.1016/j.geoforum.2021.09.014

Lundgren, J. G., & Fausti, S. W. (2015). Trading biodiversity for pest problems. *Science Advances, 1*(6), e1500558. Advance online publication. https://doi.org/10.1126/sciadv.1500558

MacKendrick, N. (2018). *Better safe than sorry: how consumers navigate exposure to everyday toxics*. University of California Press. https://doi.org/10.1525/california/9780520296688.001.0001

Montenegro de Wit, M. (2020). What grows from a pandemic? Toward an abolitionist agroecology. *The Journal of Peasant Studies, 48*(1), 99–136. https://doi.org/10.1080/03066150.2020.1854741

Núñez-Rocha, T., & Martínez-Zarzoso, I. (2019). Are international environmental policies effective? The case of the Rotterdam and the Stockholm Conventions. *Economic Modelling, 81*, 480–502. https://doi.org/10.1016/j.econmod.2018.04.013

Pereira, L. M., Drimie, S., Maciejewski, K., Tonissen, P. B., & Biggs, R. O. (2020). Food system transformation: Integrating a political–economy and social–ecological approach to regime shifts. *International Journal of Environmental Research and Public Health, 17*(4), E1313. Advance online publication. https://doi.org/10.3390/ijerph17041313

Perfecto, I., Vandermeer, J., & Wright, A. (2019). *Nature's matrix: Linking agriculture, conservation and food sovereignty* (2nd ed.). Earthscan Publications. https://doi.org/10.4324/9780429028557

Rani, L., Thapa, K., Kanojia, N., Sharma, N., Singh, S., Grewal, A. S., Srivastav, A. L., & Kaushal, J. (2021). An extensive review on the consequences of chemical pesticides on human health and environment. *Journal of Cleaner Production, 283*, 124657. Advance online publication. https://doi.org/10.1016/j.jclepro.2020.124657

Rekow, L. (2019). Socio-ecological implications of soy in the Brazilian cerrado. *Challenges in Sustainability, 7*(1), 7–29. https://doi.org/10.12924/cis2019.07010007

Romero, A. M. (2021). *Economic poisoning: Industrial waste and the chemicalization of American agriculture*. University of California Press.

Rosset, P. M., & Martinez-Torres, M. E. (2013). La Via Campesina and agroecology. In *La Via Campesina's open book: Celebrating 20 years of struggle and hope* (pp. 1–21). La Via Campesina. https://viacampesina.org/en/wp-content/uploads/sites/2/2013/05/EN-12.pdf

Russell, E. (2001). *War and nature: Fighting humans and insects with chemicals from World War I to Silent Spring*. Cambridge University Press.

Samberg, L. H., Gerber, J. S., Ramankutty, N., Herrero, M., & West, P. C. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. *Environmental Research Letters, 11*(12), 124010. Advance online publication. https://doi.org/10.1088/1748-9326/11/12/124010

Saxton, D. I. (2021). *The devil's fruit: Farmworkers, health and environmental justice*. Rutgers University Press. https://doi.org/10.36019/9780813598659

Seufert, V., Ramankutty, N., & Mayerhofer, T. (2017). What is this thing called organic? How organic farming is codified in regulations. *Food Policy, 68*, 10–20. https://doi.org/10.1016/j.foodpol.2016.12.009

Sharma, A., Shukla, A., Attri, K., Kumar, M., Kumar, P., Suttee, A., Singh, G., Barnwal, R. P., & Singla, N. (2020). Global trends in pesticides: A looming threat and viable alternatives. *Ecotoxicology and Environmental Safety, 201*, 110812. Advance online publication. https://doi.org/10.1016/j.ecoenv.2020.110812

Shattuck, A. (2019). Risky subjects: Embodiment and partial knowledges in the safe use of pesticide. *Geoforum, 123*, 153–161. Advance online publication. https://doi.org/10.1016/j.geoforum.2019.04.029

Shattuck, A. (2020). Toxic uncertainties and epistemic emergence: Understanding pesticides and health in Lao PDR. *Annals of the Association of American Geographers, 111*(1), 216–230.

Shattuck, A. (2021). Generic, growing, green? The changing political economy of the global pesticide complex. *The Journal of Peasant Studies, 48*(2), 231–253. https://doi.org/10.1080/03066150.2020.1839053

Stein, S., & Luna, J. (2021). Toxic sensorium: Agrochemicals in the African anthropocene. *Environment and Society, 12*(1), 87–107. https://doi.org/10.3167/ares.2021.120106

Stenberg, J. A. (2017). A conceptual framework for integrated pest management. *Trends in Plant Science, 22*(9), 759–769. https://doi.org/10.1016/j.tplants.2017.06.010

Svensson, M., Urinboyev, R., Wigerfelt Svensson, A., Lundqvist, P., Littorin, M., & Albin, M. (2013). *Migrant agricultural workers and their socio-economic, occupational and health conditions—A literature review* (SSRN Scholarly Paper No. 2297559). Social Science Research Network. https://doi.org/10.2139/ssrn.2297559

Uekötter, F. (Ed.). (2014). *Comparing apples, oranges, and cotton: Environmental histories of the plantation*. Campus Verlag.

United Nations Environmental Programme. (2020). Stockholm convention on persistent organic pollutants (POPs). In S. O. Idowu, N. Capaldi, L. Zu, & A. D. Gupta (Eds.), *Encyclopedia of corporate social responsibility* (pp. 2336–2336). Springer.

Vercillo, S., Weis, T., & Luginaah, I. (2020). A bitter pill: Smallholder responses to the new green revolution prescriptions in northern Ghana. *International Journal of Sustainable Development and World Ecology, 27*(6), 565–575. https://doi.org/10.1080/13504509.2020.1733702

Werner, M., Berndt, C., & Mansfield, B. (2021). The glyphosate assemblage: Herbicides, uneven development, and chemical geographies of ubiquity. *Annals of the Association of American Geographers, 112*(1), 19–35.

Willer, E. H., & Lernoud, J. (2019). *The world of organic agriculture. Statistics and emerging trends 2019* (20th ed.). Research Institute of Organic Agriculture., http://www.organic-world.net/yearbook/yearbook-2019.html

Williams, B. (2021). “The fabric of our lives”? Cotton, pesticides, and agrarian racial regimes in the U.S. South. *Annals of the Association of American Geographers, 111*(2), 422–439.

World Health Organization. (2019). *The WHO recommended classification of pesticides by hazard and guidelines to classification*. https://www.who.int/publications-detail-redirect/9789240005662

Xiuhtecutli, N., & Shattuck, A. (2021). Crisis politics and US farm labor: Health justice and Florida farmworkers amid a pandemic. *The Journal of Peasant Studies, 48*(1), 73–98. https://doi.org/10.1080/03066150.2020.1856089

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