Pesticides and Climate Change: A Vicious Cycle

Winter 2022–2023

Executive Summary

Climate change is one of the greatest challenges facing humanity today. Scientific evidence indicates that pesticides contribute significantly to greenhouse gas emissions while also making our agricultural systems more vulnerable to the effects of climate change. However, the reduction of synthetic pesticide use has been omitted from climate change solutions, and synthetic pesticide use is even presented as a climate change mitigation strategy by industrial agriculture interests.

Pesticides contribute to climate change throughout their lifecycle via manufacturing, packaging, transportation, application, and even through environmental degradation and disposal. Importantly, 99% of all synthetic chemicals — including pesticides — are derived from fossil fuels, and several oil and gas companies play major roles in developing pesticide ingredients.[1] Other chemical inputs in agriculture, such as nitrogen fertilizer, have rightly received significant attention due to their contributions to greenhouse gas emissions. Yet research has shown that the manufacture of one kilogram of pesticide requires, on average, about 10 times more energy than one kilogram of nitrogen fertilizer.[2, 3] Like nitrogen fertilizers, pesticides can also release greenhouse gas emissions after their application, with fumigant pesticides shown to increase nitrous oxide production in soils seven to eight-fold.[4, 5] Many pesticides also lead to the production of ground-level ozone, a greenhouse gas harmful to both humans and plants.[6, 7, 8] Some pesticides, such as sulfuryl fluoride, are themselves powerful greenhouse gases, having nearly 5,000 times the potency of carbon dioxide.[9]

Meanwhile, climate change impacts are expected to lead to increases in pesticide use, creating a vicious cycle between chemical dependency and intensifying climate change (see Figure 1). Research shows that declining efficacy of pesticides, coupled with increases in pest pressures associated with a changing climate, will likely increase synthetic pesticide use in conventional agriculture.[10] An increase in pesticide use will lead to greater resistance to herbicides and insecticides in weeds and insect pests, while also harming public health and the environment. The effects of higher synthetic pesticide use will disproportionately impact populations already under stress from a wide range of climate change effects, such as extreme heat and wildfire smoke. The compounded effects of climate change and pesticide use primarily fall on the shoulders of people of color — a climate and racial injustice.[11, 12, 13, 14, 15]

Adoption of alternative agricultural systems such as agroecological farming minimizes or eliminates synthetic pesticide use while increasing the resilience of our agricultural systems to better withstand climate change impacts.[16, 17, 18] Agroecology is a way of farming rooted in social justice that focuses on working with nature rather than against it. It relies on ecological principles for pest management, minimizing the use of synthetic pesticides, while prioritizing the decision-making power of farmers and agricultural workers. Agroecology and diversified organic agriculture, when paired with social justice principles, have been shown to have significant climate benefits, while supporting the health and rights of agricultural workers, Indigenous Peoples and rural communities.

Decisive action is required to reduce agrochemicals' contribution to greenhouse gas emissions and improve the climate resilience of food and farming systems. To accomplish this, policymakers should:

- Establish measurable goals in climate policies to reduce synthetic pesticide use in agriculture;
- Promote the transition to biodiverse, agroecological food and farming systems, such as by establishing and funding programs that provide increased technical assistance and incentives to farmers to adopt or continue these farming practices; and
- In line with international law, adopt regulations that uphold and promote the rights of groups most impacted by synthetic pesticide use.

Transitioning our agricultural systems to those that uplift ecological and social justice principles will not only help mitigate climate change, but also reduce the negative health impacts of industrial agriculture. While the work toward future policy and practice change continues, we can collectively support the advocacy work of impacted communities and organizations fighting for more equitable and sustainable food and farming systems right now.

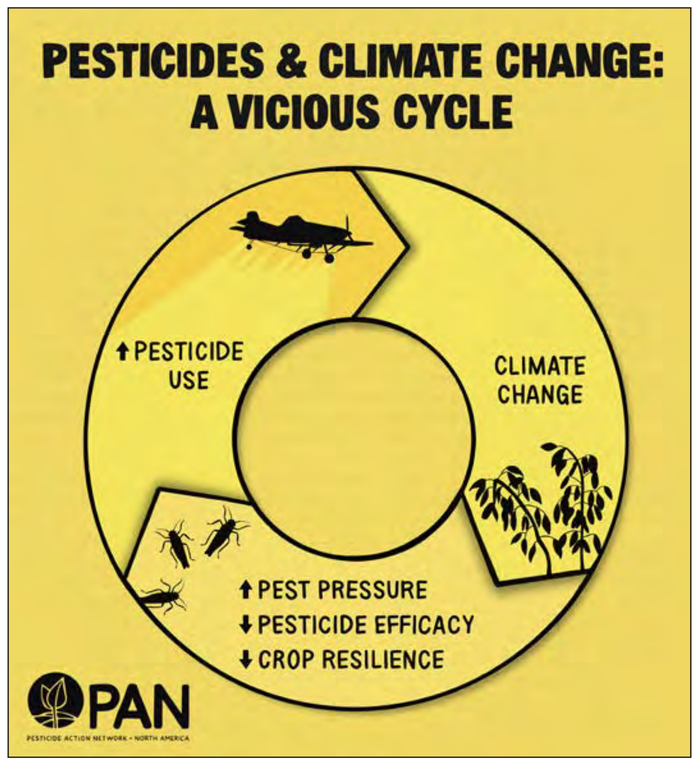


Figure 1.

Introduction

Pesticides: The foundation of industrial agriculture

In modern industrial agriculture, farm operations are viewed as ecologically simplified systems with highly controlled and monetized inputs (pesticides, fertilizers and seeds) and outputs (crops). In the absence of highly diverse and vigorous plant and soil ecosystems that provide necessary crop nutrients and natural controls of pests and diseases, these "conventional" agricultural systems rely on regular inputs of synthetic pesticides and fertilizers.[19, 20] The primary objective of conventional agriculture is to maximize short-term profits through increased yields and sales while minimizing internal costs (e.g. labor) and ignoring external costs.[21, 22] The most obvious external costs ignored by industrial agriculture are associated with human health impacts[15, 16] and the degradation of ecosystem services such as clean air, water and healthy soil.[23]

Agricultural policies and export-focused agriculture continue to aggressively promote the production of chemical-intensive commodity crops. Commodity crops are those produced primarily for trade in large-scale international markets, such as corn, rice, soybeans, wheat and cotton. These crops are among those with the greatest use of pesticides and fertilizers in the U.S. and globally.[24, 25] The United Nations Food and Agriculture Organization reported global pesticide use in 2020 at about 2.7 million tonnes (5.9 billion pounds) of pesticide active ingredients, with herbicide use at about 1.4 million tonnes (3.1 billion pounds), fungicides and bactericides at 0.6 million tonnes (1.3 billion pounds), and insecticides at 0.5 million tonnes (1 billion pounds) (see Table 1). Pesticide active ingredients are the chemicals in a pesticide formulation meant to control the target pest, while pesticide inert ingredients help the overall performance of the pesticide. Only pesticide active ingredients must legally be publicly disclosed

Geographic Area	Pesticide	2005 tonnes	2020 tonnes	% increased change
USA	Pesticides (total)	388,275	407,779	5.0
USA	Herbicides	190,509	255,826	34.3
USA	Insecticides	61,689	65,771	6.6
USA	Fungicides and Bactericides	22,680	24,040	6.0
World	Pesticides (total)	2,280,626	2,661,124	16.7
World	Herbicides	1,043,223	1,397,465	34.0
World	Insecticides	470,360	471,238	0.2
World	Fungicides and Bactericides	529,860	605,986	14.4

Table 1. Pesticide use in 2005 and 2020. Source: Food and Agriculture Organization of the United Nations. FAOSTAT Online Database. https://www.fao.org/faostat/en/#data/RP. Accessed on Sept. 7, 2022.

Note: The totals also include pesticide groups not listed, such as mineral oils and rodenticides. Not all countries provide data for all pesticide groups in the FAO database.

on pesticide labels. Inert ingredients are considered company proprietary information, even though many are toxic chemicals.[26] As Table 1 displays, while the use of pesticides overall increased 17% between 2005 and 2020, herbicide use increased 34%,[27] with China, the U.S., Argentina, Thailand and Brazil as the top pesticide consumers.[25] These pesticide use estimates likely underestimate actual use significantly because pesticides applied as seed treatments are commonly used in the U.S. but are not regulated or included in the UN Food and Agriculture database.[28, 29, 30, 31]

California uses over 200 million pounds (almost 91 thousand tonnes) per year of pesticide active ingredients, or 18% of the pesticides used in the United States.[32] While the state produces relatively few commodity crops, it produces over a third of the country's vegetables and two-thirds of the country's fruits and nuts.[33] The top crops for pesticide use include almonds, grapes, tomatoes, strawberries and oranges.[32] The pesticide application rate on California cropland is about 4.5 times the national average.[12] Higher application rates are driven primarily by the higher value of fruits and vegetables (compared to major U.S. commodity crops), which could result in significant profit losses if crop damage from pests were to occur.[34] The synthetic pesticides used in the greatest volume in California are fumigants and the herbicide glyphosate.[32] Fumigant pesticides are gaseous pesticides applied to soil to control soil-borne pests and diseases. Despite high rates of agricultural production (and synthetic pesticide use), many agricultural counties in California report the highest rates of food insecurity and poverty in the state, which particularly affects Latinx children.[35]

While the use of genetically-engineered (GE) crops is often touted as a tool for pesticide reduction,[36] scientific research shows the opposite to be true.[37] GE crops are often crops that have been genetically modified to be resistant to a specific pesticide, so that farmers may apply the pesticide and kill or control surrounding pests without damaging their crop. However, the widespread adoption of GE crops has led to the emergence of herbicide-resistant weeds, causing farmers to apply more herbicides.[37] For instance, in the United States, the introduction and widespread planting of herbicide-resistant crops led to an increase of 527 million pounds (239,000 tonnes) of herbicide use from 1996–2011, and caused an overall 7% increase of herbicides and insecticides.[37] The use of glyphosate (the active ingredient in Roundup — often applied to genetically engineered Roundup-tolerant crops) in the U.S. increased 300-fold between 1974 and 2014 to 250 million pounds (113,400 tonnes) accounting for about 19% of global sales.[38] Despite decades-long use of GE cotton designed explicitly to reduce insecticide use, cotton is one of the world's most pesticide-intensive crops.[39] Cotton production occupies 2.4% of the world's agricultural land but uses 4.7% of the world's pesticides, and specifically 10% of the world's insecticides.[40] This increasingly high use of pesticides negatively impacts both the environment and human health.

Research shows that intentional diversity in cropping systems can provide natural pest control, improve soil health, decrease weed biomass, attract beneficial organisms, and improve overall production.

The human and biodiversity impacts of pesticides use

Health impacts from exposure to hazardous pesticides include both acute illnesses such as skin rashes, gastro-intestinal and respiratory illnesses, and central nervous system problems.[41, 42] In addition, pesticide exposure is associated with many chronic diseases including cancers, reproductive and developmental disorders and long-term neurological dysfunction.[43] A recent review of acute pesticide poisoning cases in 141 countries estimated that about 385 million cases of unintentional, acute pesticide poisoning occur annually worldwide, including around 11,000 fatalities.[15] Based on a global farming population of approximately 860 million, this means that about 44% of farmers are poisoned by pesticides every year.[15]

In addition to farmers, those most directly affected by the use of hazardous pesticides in agriculture include agricultural workers, residents of rural communities, and residents in communities where pesticides are produced and where pesticide wastes are dumped.[11, 44, 45, 46] In the U.S., people living in these pesticide-impacted communities are disproportionately low-income and people of color.[11] These communities experience acute pesticide poisonings, chronic health effects like cancer, and developmental harms, including serious learning disabilities among children.[15, 47, 48] In these communities, the primary routes of exposure are contaminated air and water.[49, 50] For people not living and working in high-risk communities, the primary routes of exposure to hazardous pesticides are the food they eat and the water they drink.[51, 52] Because children eat, drink and breathe more per pound than adults, and because their bodies are actively developing, they are particularly vulnerable to pesticides in their environments and in their food.[48, 53]

For farmworkers, primary routes of exposure are from pesticides in the air, contact with pesticide residues on crops, or when mixing, loading or applying pesticides.[54] The effects of exposure are exacerbated by effects of climate change such as high heat, which leads to heat stress and makes the human body more susceptible to pesticides, increasing the risk of long and short-term health effects.[12] In hot weather, agricultural workers are faced with the tradeoff between increased heat stress from wearing gear to protect themselves from pesticides and not using protective gear to lower their body temperature.[55] In addition to harsh working conditions, farmworkers also routinely experience inadequate access to healthcare.[56] Because of their residence in agricultural communities, together with their enhanced susceptibility, farmworker children suffer some of the most severe health impacts from agricultural pesticide use.[48]

Pesticides also harm the biodiversity that our agricultural systems and natural world depend upon. They have been long known to directly poison or lead to population declines of birds, mammals, amphibians and beneficial plant and insect species.[57] They are now widely recognized to be among the top drivers of biodiversity losses worldwide.[58, 59] Neonicotinoids, a type of insecticide, have received public attention due to their significant harm to pollinators, like honey bees.[60, 61] Honey bees play essential roles in pollinating agricultural crops, and are responsible for about $15 billion in added crop value in the U.S. per year.[62] Pesticides also have profound effects on soil macro- and micro- fauna, which in turn impact the long-term structure and function of agricultural soil.[63] For example, the use of insecticides and other pesticides can result in the death of soil invertebrates like earthworms.[64] Soil invertebrates are crucial in creating structure and aeration in soils and in preventing soil compaction, roles that help soil retain water and perform other desirable functions.[64]

Climate policy ignores synthetic pesticides

Globally, food systems account for over one-third of all greenhouse gas (GHG) emissions, with 31% of that from agricultural production, including the production of associated inputs like pesticides.[65] While agriculture's contributions to climate change are increasingly recognized in public policy, there are two glaring issues with current approaches to the problem. First, the role of pesticides in GHG emissions is infrequently addressed, and farming solutions like agroecology that would reduce their impact are rarely considered. For example, certain practices labeled climate-smart, such as no-till, often rely heavily on synthetic herbicides to control weeds on conventional farms and can lead to increased weed resistance to herbicides.[66] Second, many proposed solutions would not result in meaningful GHG emission reductions, or would further exacerbate inequities in food and farming.

An example of a false solution is precision agriculture, which promises to reduce the use of petroleum-derived pesticides and fertilizers by using computer-aided technologies to more accurately determine need (pest presence) and then more accurately apply pesticides to intended targets.[67] However, precision agriculture maintains a system dependent upon chemical and energy-intensive technologies and materials, while diverting attention from and investment in more effective climate-friendly strategies in agriculture that have additional social and public health co-benefits, such as agroecology. Precision agriculture also increases the power and control of agrochemical companies, many of which own the precision agriculture platforms and the data inputted by farmers.[68]

Another flawed solution, carbon markets, allows agribusinesses or farmers to sell carbon credits to corporations to "offset" continued greenhouse gas emissions — perpetuating reliance on fossil fuels. Carbon markets have a poor track record in terms of long-term climate mitigation, and have been shown to worsen economic and racial disparities.[69]

In contrast, farming systems that do not rely on use of synthetic pesticides, such as those based on agroecological principles or diversified organic farming, can reduce GHG emissions and increase carbon sequestration.[70, 71, 72] They also increase farm resilience to climate change and pests by enhancing many ecosystem services such as water quality and water availability to crops, soil health, crop resilience to pests and disease, and greater pollinator and natural pest control resources.[73] Utilizing ecological pest and crop management practices reduces the need for petroleum-derived pesticides and fertilizers,[74] and therefore reduces associated emissions of greenhouse gases. Public policy should support demonstrably effective, ecologically based practices that mitigate climate change while also making farms and rural communities more resilient as climate conditions change.[69] Beyond practice change, ultimately a societal transformation of agricultural systems is urgently needed to avert further exacerbation of today's climate, food and biodiversity crises. International experts agree that, unlike incrementalist tweaks that leave a fundamentally fossil-fuel dependent system in place, agroecology offers a transformative approach.[17]

Impacts of Climate Change on Pests and Pesticide Use

Scientists expect climate change to dramatically alter how toxic chemicals like synthetic pesticides are used, adversely impacting the environment and public health. Research detailed below shows that the effects of our changing climate will likely lead farmers to increase the use of synthetic pesticides unless we begin to transition toward safer forms of agriculture that use smaller-scale, diversified agroecological practices.

How agricultural pests will respond to climate change

Climate change is expected to have variable effects on agricultural pests, depending on regional climatic changes, type of cropping systems and type of pest.[75] Pressure from agricultural pests — including insects, other animals, weeds and diseases that impact crop productivity — can increase or decrease depending on regional climatic shifts, such as changes in precipitation and temperature.

The latest science demonstrates that in the era of rising temperatures, crop resilience (the crops' ability to withstand external forces, such as climate impacts or pests) is decreasing on farms, making crops more vulnerable to pests generally. Heat stress and changing rainfall patterns both decrease crop resilience to pests.[76] Drought conditions in particular, which are expected to worsen in many regions, can weaken plants' natural defenses against pests, and changes in plant biology due to drought may attract pests.[77] Insects can sense changes that indicate plants are more vulnerable, such as higher plant surface temperatures, leaf yellowing, biochemical changes, and possibly even the sound waves produced when water columns in plant tissue break apart due to water stress.[78] Given that 80% of the world's cropland is rainfed, global crop yield is highly susceptible to changes in rain patterns[79] and the increased pest pressures that can accompany changes in precipitation.

In addition to decreasing crop resilience, higher global temperatures will likely stimulate a general increase in the rate of insect development and population growth in certain regions, such as the U.S. Midwest.[76] Rising temperatures and shifts in moisture levels can increase or shift insect pests' geographic range and their ability to survive through the winter.[77] Researchers have predicted that rising CO_2 and temperature will accelerate insect pests' metabolism and consumption, ultimately leading to declining crop yields.[80]

Scientists predict climate change will negatively affect certain natural enemies of insect pests (also referred to as beneficials), further increasing crops' susceptibility to insect pest damage. For instance, climate change could cause insect pests to migrate to new areas where their natural enemies may be unable to follow, or the synchronization between the life cycles of pests and their natural enemies may be disrupted.[81, 82] Pesticide applications are known to be harmful to beneficial organisms that control pest populations, and predicted increases in pesticide applications would further reduce these beneficial populations. Specific impacts of a changing climate on these interactions between pests and beneficials are often regional- and cropping system-dependent.

Researchers have also predicted that changing environmental conditions, such as CO_2 and temperature increases, will likely increase weed pressures in cultivated crops. Weeds are more likely to be resilient and better adapted to climate change effects than cultivated crops because they have more diversity in their gene pool and greater ability to physiologically acclimate to different environmental conditions.[83] Climate change is also anticipated to introduce weeds to new regions and shift the composition of regional weed species, particularly favoring invasive species.[84] Expected increases in herbicide applications would also increase the prevalence of herbicide-resistant weeds.[84] These factors suggest that weeds will have an increased ability to outcompete agricultural crops in many regions, leading to declining yields.[85]

Researchers find certain climatic changes affect different pests in different ways. For instance, smaller pests, such as aphids, mites or whiteflies, can be washed away during intense precipitation.[86] In areas that might experience more periods of prolonged precipitation, plant fungal and bacterial diseases are likely to become more common.[75] Therefore, specific regional climatic impacts will have a significant influence on which pests become more prevalent, and more comprehensive research is needed to predict effects for each specific region, crop and pests. However, certain agricultural system shifts, like diversifying our agricultural systems, could serve as universal solutions since they increase ecosystem resilience and therefore agricultural resilience to climate change, regardless of region.[87]

What does this mean for pesticide use under climate change?

The latest science reveals that climate change will likely increase the movement of pesticides away from their intended targets, polluting the environment and endangering public health. Increased temperatures are anticipated to result in more pesticide volatilization (when pesticides transform into a gas)—meaning more pesticides will end up in our air, rather than on their application target.[88] Volatilization is a key source of pesticide drift, which can cause pesticide poisoning for anyone exposed to the toxic vapor.[89] An increase in severe rain events is expected to increase pesticide loss to our waterways, with one study showing concentrations of pesticides in waterways to be 84–2100% higher after 100-year storms as compared to two-year storms.[90]

Climate change is also expected to affect pesticide degradation, or the process by which pesticides break down in the environment. The breakdown products of the pesticide degradation process can either be less toxic or at times more toxic than the original product.[91, 92] Researchers anticipate that certain climate change effects will cause faster pesticide degradation, meaning pesticides will break down faster and become less effective over time. For instance, increasing soil temperatures have been linked to reduced duration of weed control by herbicides because of faster degradation. In contrast, low soil moisture has been linked to slower degradation of herbicides.[93] However, overall, faster pesticide degradation is expected, likely leading to more frequent pesticide applications at higher application rates.[10] These combined factors are expected to contribute to a likely increase (both in volume and frequency) of pesticide use across a variety of products.[94]

Greenhouse Gas Emissions of Pesticides

In recent decades, the greenhouse gas emissions and other negative environmental impacts of synthetic nitrogen fertilizers have garnered a great deal of attention.[95, 96] Although more nitrogen fertilizers are used in agriculture than pesticides, comparatively little attention has been directed toward the greenhouse gas emissions that result from pesticide production and use. This is despite evidence that manufacturing one kilogram of pesticide active ingredient requires, on average, about 10 times more energy than one kilogram of nitrogen fertilizer.[2, 3] As nations seek to mitigate climate change and develop more sustainable agricultural systems, it is crucial to measure and reduce the GHG emissions associated with pesticide use.

Current scientific literature is divided into two focus areas for GHG emissions of pesticides. Some studies focus on the emissions that result from the production, transportation, and field application of pesticides, and other studies focus on the short- and long-term GHG emissions that result from pesticides' interactions with the environment after application. Virtually no studies calculate the GHG emissions of pesticide use over the full life cycle of the chemicals, which likely causes underestimates of true emissions. Research to date also omits the emissions associated with pesticide waste, such as obsolete stockpiles (stockpiles of pesticides that have expired, been made illegal to use or are otherwise unwanted) and their disposal through burning and other methods — practices common in parts of the Global South.

GHG emissions associated with pesticide production, transportation, and field application

The greenhouse gas emissions associated with the production, transportation, and application of pesticides are linked to fossil fuel consumption during these processes. Importantly, 99% of all synthetic chemicals — including pesticides — are derived from fossil fuels, and several oil and gas companies play major roles in developing pesticide ingredients.[1] Since World War II, pesticides have typically been synthesized from petroleum or petroleum by-products.[97] ExxonMobil, ChevronPhillips Chemical and Shell all produce pesticides or their chemical precursors.[1] Many pesticides are also coated in microplastics, which are derived from fossil fuels, to ensure more controlled release of the product.[98] Multiple pesticide corporations self-report high CO_2 equivalent emissions (CO_2e) related to their operations. For instance, 9.8 million tonnes of CO_2e directly or indirectly resulted from Syngenta's operations in 2021.[99] This is equivalent to the annual carbon dioxide emissions of more than 2 million passenger vehicles.[100] Bayer's Crop Science Division, responsible for their pesticide operations, reported that their direct emissions totaled about 2.7 million tonnes of CO_2e in 2021.[101] The company also stated that 8.94 million tonnes of CO_2e emissions were linked indirectly to the company's value chain in 2021, though it did not specify how much of those emissions were related to their Crop Science division.[101]

Although more updated research is needed, researchers have calculated the energy use associated with the production of specific pesticides, which can then be used to estimate CO_2e emissions. The production of herbicides creates between 18.22 and 26.63 kilograms of CO_2e per kilogram produced on average.[2] The production of insecticides creates between 14.79 and 18.91 kilograms CO_2e per kilogram and the production of fungicides creates between 11.94 and 29.19 kilograms CO_2e per kilogram on average.[2] The GHG emissions of glyphosate, the world's most popular herbicide, produces 31.29 kilograms of CO_2e per kilogram while other pesticides produce greater than 40 kilograms CO_2e per kilogram.[2] To put this in perspective, the energy used to produce the amount of glyphosate used globally in 2014 equals the energy needed to fuel about 6.25 million cars for one year.[102]

These estimates of GHG emissions by pesticides only factor in the energy used to produce the active ingredients. A true estimate must also include the energy needed to formulate the pesticide products and manufacture the inert ingredients, which can make up the majority of a product. For instance, inert ingredients make up as much as 50–75% of glyphosate products.[103] More than 500 of these so-called inert ingredients have been or are currently used as active ingredients, yet due to proprietary protections, the identification and volume of these ingredients are kept secret from the public,[26] making it impossible to calculate energy requirements for the manufacture of pesticide products in their entirety.

The transportation and application processes add to the GHG emissions associated with pesticide use. The farther a pesticide must travel to reach its application site and the more times per season that a pesticide is applied, the greater the pesticide use emissions. Pesticide transportation and application produce fewer emissions than pesticide manufacturing, but research shows these emissions are still significant.[104]

Short- and long-term GHG emissions post-pesticide application

GHG emissions that result from pesticide use are not limited to the emissions involved in pesticide manufacturing, transportation and application. Additional emissions result from the release of the pesticide into the environment and the pesticide's subsequent interactions with organisms in the soil and with the atmosphere, both in the short- and long-term.

Some pesticides are themselves greenhouse gases. The fumigant sulfuryl fluoride (used to fumigate commodities during transport and storage), is a powerful greenhouse gas. Emitting just one ton (0.91 tonnes) of sulfuryl fluoride is the equivalent of emitting 4,780 tons (4,336 tonnes) of CO_2.[9, 105] Meanwhile, other pesticides interact with the environment to produce greenhouse gases in a variety of ways. Since often less than 0.1% of applied pesticides reach their target,[106] with the rest ending up on plant leaves, in the soil, in water, or in the air,[107] the implications for GHG emissions of these pesticides' fate (their off-target movement) in the environment is significant.

Pesticide application can produce greenhouse gases by emitting volatile organic compounds (VOCs). VOCs are compounds that easily volatilize into gases that react with nitrogen oxides (NOx) and UV rays to produce ground-level ozone.[108, 109] Ground-level, or tropospheric ozone is a significant greenhouse gas that causes respiratory problems in people[7] and, according to the U.S. Department of Agriculture, causes more damage to plants than all other air pollutants combined.[8] Studies have found that as much as 80 to 90% of applied pesticides may volatilize within a few days of application.[110, 111] Fumigant pesticides are typically associated with the most VOC emissions.[6] However, many other pesticides produce VOCs as well. Monitoring in California's San Joaquin Valley has shown that 76% of pesticide VOC emissions are from non-fumigant pesticides.[112]

While the adverse effects of physical soil disturbances such as intensive tillage on soil micro- and macro-organisms has been widely researched and documented, far fewer studies have focused on the impacts of chemical disturbances such as pesticides and herbicides on soil life. However, studies to date indicate that long-term pesticide use has serious impacts on soil health. Many different pesticides have negative effects on beneficial bacteria and fungi in the soil.[113] These soil microbial and fungal communities play a crucial role in soil carbon sequestration.[114] Research indicates soil microbes are responsible for producing the most stable forms of soil organic carbon that will remain in the soil for long periods of time.[69] Soil microorganisms serve a number of other important functions, such as building healthy soil and by extension healthy crops, and increasing crop resilience.[115] They also regulate carbon and nitrogen cycles that control emissions of carbon dioxide, methane and nitrous oxide (N_2O).[116]

When researchers studied the effects of soil fumigants on N_2O emissions, they found that the use of chloropicrin — a commonly used fumigant — could increase N_2O production seven to eight fold.[5] Nitrous oxide is a greenhouse gas 300 times more potent than carbon dioxide. Similar effects on nitrous oxide production have been documented after application of other pesticides and these effects were evident even after 48 days for some applications.[117, 118] Researchers have suggested that the large N_2O emissions associated with certain pesticide applications may be a result of impacts on soil microbes.[117, 118] Thus, pesticide use can increase GHG emissions, while negatively impacting soil microbial activity and soil health.

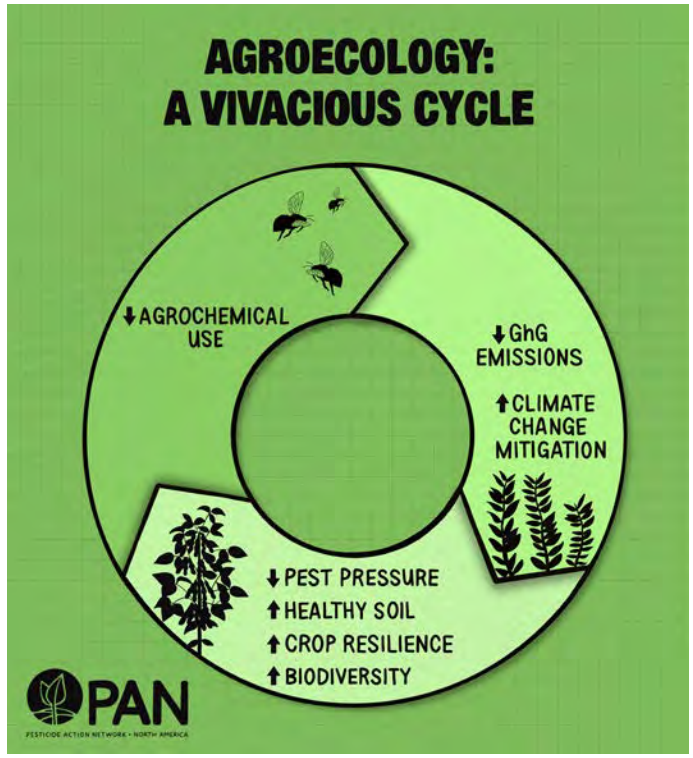
Solutions: From Vicious to Vivacious Cycle

Current conventional agricultural systems reliant on synthetic chemicals compromise the integrity and function of the agroecosystem and its ability to support vigorous, pest-resistant crops. These systems necessitate continual soil disturbance and frequent application of pesticides and fertilizers — **a vicious cycle of ecosystem destruction.**

In contrast, highly diverse, agroecological cropping systems can build healthy soil and above-ground ecosystems that supply nutrients and natural pest control without added synthetic chemicals[16] — **a vivacious cycle of nutrients and pest prevention.**

We've seen growing and widespread high-level support for replacing the currently dominant chemical-input approach to agriculture with a biological approach. A number of United Nations agencies and high-level expert reports have recognized the need for agroecology.[17, 119, 120, 121] These evolving perspectives have been informed by decades of research and millennia of Indigenous Peoples' and farmers' practices using agroecological approaches that have shown multiple benefits. Benefits include improved yields, greater profitability and increased gender equity.[16] Agroecological farming is also more resilient to climate change effects[122, 123] and mitigates climate change.[124] Additional benefits of agroecological farming include better public health, improved food security and sovereignty, and enhanced biodiversity and social benefits, such as better cooperation between farmers and communities.[16, 125, 126]

However, many structural barriers exist that prevent farmers from transitioning to agroecological, diversified farming practices. These barriers must be addressed through government policies that support more secure land tenure, better access to capital during transition, and market incentives.[127, 128] A full list of policy recommendations can be found below.



Call to Action

Governmental and collective action must be taken in order to avoid the worst effects of today's climate crisis on our food and farming systems. Decisive action is urgently required to mitigate climate change and strengthen climate resilience. Significant reductions in use of and reliance on synthetic pesticides, combined with transitions to least-toxic, diversified agroecological farming can help us reach these necessary goals.

We recommend the following priority actions:

1. Governmental policies addressing climate change must include synthetic pesticide use reduction targets as a key strategy in order to mitigate and adapt to climate change as well as achieve climate justice.

   These targets should include meaningful, measurable, and legally binding commitments to:

   a. Reduce synthetic pesticide use by 50% by 2030 (in line with the European Union's Farm to Fork Strategy) and by 90% by 2050;

   b. Reduce pesticide toxicity by 50% by 2030 and by 90% by 2050. Reducing pesticides' level of toxicity to the human body and environment is a critical goal to avoid incentivizing pesticides that can be applied at lower rates, but pose higher levels of toxicity; [129]

c. Phase out highly hazardous pesticide (HHP) use by 2030. [130] The use of HHPs result in disproportionately higher harm to public health and the environment, and therefore must be phased out on an expedited timeline; and

d. Transition 30% of total agricultural acreage to agroecology or diversified organic agriculture by 2030, similar to the EU's Farm to Fork Strategy.

Without measurable targets as guideposts to governmental action, policies could result in government spending without achieving meaningful reductions in use of synthetic pesticides generally, and highly hazardous pesticides in particular. We also recognize that countries around the world have a range of agricultural systems and pest management practices, and recommend that these goals be tailored to regional considerations in ways that prioritize the health and wellbeing of rural communities, Indigenous Peoples, workers, and other historically oppressed populations.

2. Governments must significantly increase public investment in farmer-centered participatory research and technical assistance, and direct financial support to enable farmers to transition to agroecological approaches. Public investments should:

    a. Increase knowledge-sharing opportunities for farmers and agricultural workers to share their expertise and learn more about agroecological farm management practices;

    b. Expand the capacity and quality of technical assistance providers in providing relevant support to farmers — both those practicing ecological farming, as well as those seeking to transition to an agroecological approach;

    c. Direct financial assistance, especially to small-scale farmers and farmers of color, to adopt or continue agroecological farm management practices; and

    d. Increase government procurement programs that incentivize the market growth of products grown on agroecological or diversified organic farms.

3. Governments must adopt policies that support the rights of agricultural workers and other historically oppressed groups.

    Policies should support alternative agricultural systems like agroecology or diversified organic agriculture where decision-making power is held by those most affected by synthetic pesticide use and exploitative farming practices, such as farmers of color, small-scale farmers, farmworkers, environmental justice communities and Indigenous Peoples. If these communities' rights to land, clean air and water, safe working conditions and healthy food were respected by decision-makers, we would not have the chemical-laden, industrial agricultural system we see today. Recommended policies to ensure fulfillment of the rights of these groups include policies that:

    a. Protect workers' rights to health, safety and a living wage; outlaw and prevent abusive and harmful working conditions; grant an immediate pathway to citizenship for agricultural workers; and protect their right to freedom of association (the ability to unionize and vote anonymously);

    b. Ensure secure land access and ownership for the groups mentioned above, all of whom have historically been denied land ownership rights, including through reparations or land back*; and that

    c. Support the leadership and agency of those most impacted by synthetic pesticide use to define and build solutions.

Collective Action

History has shown us how much more power we have when we act collectively rather than individually. We recommend that individuals join collective movements that support the rights of small-scale farmers, farmworkers, Indigenous Peoples and environmental justice communities to make decisions about the land that they steward.

Individuals can participate in collective action with PAN and other organizations and social movements fighting to support these rights and pass agricultural policies that minimize synthetic pesticide use and its associated harms.

Together, we have the power to transform agriculture and achieve social, environmental and climate justice.

* Land back is a movement led by Indigenous Peoples to uphold their sovereignty and return land back to the people who occupied it before colonization.

Notes

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