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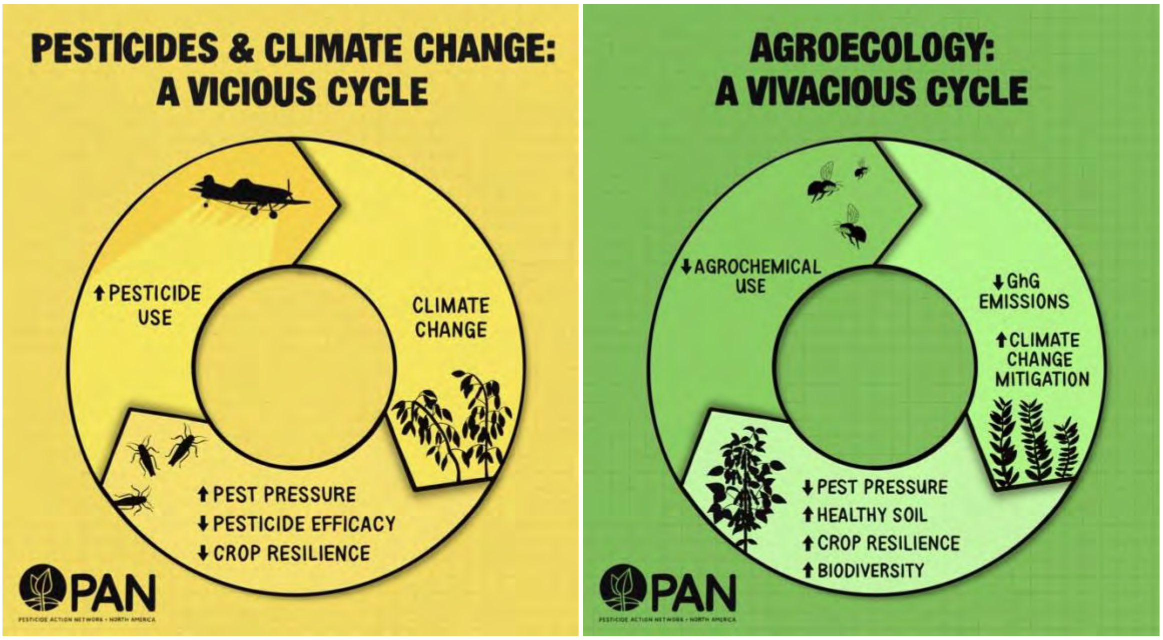
Pesticides and Climate Change: From a *Vicious* to a *Vivacious* Cycle



Recommendations

1. Governmental policies addressing climate change must reduce synthetic pesticide use in order to mitigate and adapt to climate change and achieve climate justice.
    a. Phase out highly hazardous pesticide (HHP) use by 2030, as set out in binding and non-binding international agreements.[1]
    b. Supporting practices that promote healthy soils as a carbon sink and identifying and implementing additional ways to reduce agricultural emissions of N_2O and ozone
    c. Taking a more comprehensive approach to the inventory of agricultural emissions by including emissions from transport, production, and volatile organic compounds (VOCs) in pesticides
    d. There is a need for current information on greenhouse gas (GHG) emissions from pesticides during their life cycle — for manufacturing, packaging, transport, application, and disposal

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.
    a. Examples include: increasing knowledge-sharing and learning opportunities for farmers and agricultural workers; increasing financial incentives through local food

purchasing programs;[2] fair trade policies; and financial and technical assistance for farmers practicing or interested in transitioning to agroecological approaches to farming.

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

Introduction

There is a strong scientific consensus that human-caused greenhouse gas (GHG) emissions exacerbate climate change. Governmental policies must aim to reduce GHG emissions, because climate change is a threat to environmental and human health.

This document follows on PAN's 2023 report, *Pesticides and Climate Change: A Vicious Cycle*.[3] A shortened version of the recommendations from the report are presented. However, with recent changes in US policy, progress towards reducing GHG emissions may only take place internationally or in certain US states.[4] [5] Government funding for climate change research and reporting on GHG inventories should continue, so that policies to limit GHG emissions are informed by current scientific research.

All areas of agriculture have management options that will reduce GHG emissions.[6] Fertilizers are widely acknowledged as an agricultural input that significantly contributes to GHG emissions.[7] Pesticides are also a major agricultural input that contribute to GHG emissions. Pesticides contribute to climate change throughout their "life cycle," including the extraction of their base materials (fossil fuels), manufacturing, packaging, transport, application, environmental dispersion and disposal. However, there is less available information on pesticides' contributions to GHG emissions, as this area is not as well studied. The discussion here and in the previous report focuses on agricultural crops, though livestock production also emits GHGs and is adversely affected by climate change as well.

Food systems contribute to GHG emissions

Globally, food systems account for over one-third of all GHG emissions, with 31% of that from agricultural production, though these estimates do not include the manufacturing of pesticides.[8] An analysis of the US food system that excluded parts of the life cycle reported that agrichemicals manufacturing represents the third largest energy consumer on farms (4.9%).[9] In the US, agriculture accounted for 10% of GHG emissions by economic sector.[10] Agriculture provides both "sources and sinks" of GHG and the top three emissions by mass are: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[11] The most recent GHG inventory from the U.S. reported that between 1990 and 2022, CO_2 and CH_4 agricultural emissions increased by 21% and 14.5%, respectively. Agricultural emissions of N_2O fluctuated annually and overall increased by 1.9%.[12]

Adverse effects from climate change on agriculture include increasing frequency of severe drought and flooding, the degradation of soil and water resources; health challenges to rural populations and livestock; and effects on the vulnerability and adaptive capacity of rural communities.[13] Broadly speaking, the lack of availability, accessibility, and usability of food are the most negative impacts of climate change on agriculture and the food supply.

Climate change and its effects on the food system

In the US, climate change effects on agriculture will impact rural communities the most, because of their role in the food system as producers and as stewards of the land. Rural communities are the primary site of intensive agricultural pesticide usage and as such, bear much of the burden of environmental and human health impacts of pesticide use. Adapting the agricultural system to better respond to the changing conditions caused by climate change will build resilience in rural communities in the U.S. and around the globe.[14]

In addition to its direct negative impacts on the food system, climate change directly and negatively affects human health. Extreme temperatures increase the risk of heat stress in agricultural workers, particularly farmworkers.[15] Wildfire events increase exposure to pollutants from wildfire smoke and dust for farmworkers where they work and live.[16]

Agroecology provides a robust set of solutions to the environmental and economic pressures and crises facing agriculture today. Agroecology is an economically viable and socially just approach to sustainable agriculture and food systems, grounded in ecological and social principles and the integration of science with local and Indigenous knowledge and practice, and the political approach of food sovereignty.[17]

Agroecological approaches include good soil management, which help farmers adapt to climate change by creating a system that is more resilient to extreme weather events. Healthy soils can act as a sink for GHG by sequestering (or capturing) large amounts of CO_2, stored as soil organic matter (SOM). As SOM increases, so does the system's ability to hold water, reducing the impacts of drought and its ability to more effectively move water through the soil profile and thus decrease the impacts of large rain events.[18]

Impacts of climate change on pests & pesticide use

The changing environment will alter selection pressures (meaning how they adapt and survive) on weeds, affecting their range, composition, and competitiveness, potentially with a strong effect on invasive species.[19] Rising CO_2 will stimulate photosynthesis and plant growth, and altered temperature and precipitation will affect all aspects of weed biology. There is also evidence that CO_2 increases plant water-use efficiency.[20] Herbicide efficacy may also shift, for example there is potential for reduced efficacy among those herbicides that act as enzyme inhibitors.[21]

Selection pressures affect weed populations — for example, the widespread use of herbicides results in the rapid rise of herbicide resistant weed populations. This evidence suggests that understanding more about weeds' responses to selection pressures from a changing climate will be fundamentally important for managing weeds in agriculture.[22]

Warming temperatures may increase insect populations — both beneficials and pests. Temperature fluctuations can double the insect metabolic rate for each 10-degree Celsius increase.[23] However, the effects of climate change on pest abundance and crop loss may not be uniform. An analysis of responses of insect pests to a changing climate indicated mixed responses, though most of the case studies indicated increased severity of pests.[24]

Long term trends in invertebrates, including those providing ecosystem services (i.e., pollination, pest control, and nutrient recycling) in UK cereal fields were studied from 1970 to 2011. Pesticide use had a negative effect on long term trends in abundance for a majority of insects. Only one type of insect (a wasp) was found to increase in abundance correlated with temperature increase and pesticide use. The analysis of pesticide use on the cereal fields indicated a long-term trend of increased percent spray area for insecticides as well as herbicides and fungicides. Environmental factors like temperature and rainfall were also correlated with effects on insect populations. The study's results indicated that pesticide usage was more important in explaining the trends in invertebrate populations than temperature change.[25]

Climate change will make monitoring of pests even more important in developing adaptive strategies. One study suggested that integrated pest management practices will likely need adaptive changes in order to be more effective.[26] Solutions such as diversifying systems as a strategy to reduce pest pressures, could serve as universal solutions since they increase ecosystem resilience and therefore agricultural resilience to climate change, regardless of region.[27]

Apples, sugar beets, and grapes: Emissions from pesticide & fertilizer use in Austria

In addition to production and transportation, field cropping systems and pesticide type influence GHG emissions.[28]

Many estimates of GHG agricultural emissions fail to account for the contribution of production and transport associated with agrochemicals. Parts of production and transport, such as fuel or other inputs used in the life cycle of fertilizers, are not accounted for as agricultural emissions.[29] One example from the International Panel on Climate Change is fuel consumption on farmland, which is accounted for as part of energy and transport emissions, not as agricultural emissions.[30]

GHG emissions associated with pesticides are frequently not accounted for, leading to a less comprehensive understanding and underestimation of agricultural GHG emissions. In addition, data on GHG emissions pesticide production are very limited. The two most recent papers summarized information on pesticide GHG emissions that were 10 to 40 years old, from the 1980s to the

2000s.[31] The Austrian study discussed in this section relied on one of these two papers.[32] There is a notable data gap for recent data on GHG emissions associated with pesticide production and use.

In Austria, GHG inventories don't attribute pesticide-related emissions to agriculture, nor are emissions from products made abroad included.[33] The data that have been used to estimate emissions from pesticides should be updated, and ways to improve those methods should be explored, as this is not well studied.[34] PAN's previous report discussed aspects of the GHG emissions associated with pesticide production, transportation, and application.[3]

An analysis examining three pesticide-intensive crops (apples, grapes, and sugar beets) in Austria from 2000 to 2019 examined both total GHG emissions related to pesticides and fertilizers, as well as emissions for each of those agrochemicals. The study found that herbicide use decreased by 29%, while the usage of insecticides and fungicides increased by 58% and 29% respectively, with the associated CO_2 emissions showing similar patterns. These increases in pesticide use were also related to decreases in arable farmland for each of these crops. The cumulative production-related GHG emissions for pesticides from 2000 to 2019 were estimated at 331,279,525 kilograms of CO_2 equivalent emissions, with herbicides accounting for 55.6%, fungicides for 40%, and insecticides for 4.4%. Apples had the greatest total pesticide-related GHG emissions for production and application, which accounted for 51% of the total GHG emissions.

A comparison of GHG emissions per kilogram for pesticide production indicated that GHG emissions for pesticide production were much higher than for fertilizer production. However, due to the intensive application of fertilizers per hectare, fertilizer use on the crops still had higher total GHG emissions than pesticides. Compared to sugar beets (12%), a high share of pesticide-related GHG emissions was observed in both apples (51%) and wine grapes (37%), which are known to be pesticide-intensive. N_2O emissions were not considered for the study.[33]

Pesticides and GHG emissions: Volatile organic compounds

Emissions of GHG into the air occur directly when pesticides are applied and afterwards, when the formulation volatilizes into the air.[35] California is a major agricultural state and is the only US state that reports on a VOC emission inventory for pesticides, as well as the only state with detailed publicly accessible annual reporting on statewide pesticide use[36]

Pesticide formulations, especially emulsifiable concentrate formulations, often have volatile organic compounds (VOCs) that help dissolve active ingredients. VOCs are not directly GHGs, but they are precursors to GHGs, and they have indirect effects on climate change by reacting with other compounds in the atmosphere to form GHGs.[15] For example, VOCs can form secondary pollutants such as ozone and $PM_{2.5}$ after evaporating.[37]

Ground-level ozone is an important GHG and human exposure to this air pollutant negatively affects human health.[15] In addition to human health effects, ozone pollution also causes damage to plants.[38] In California, the San Joaquin Valley has high levels of ozone pollution and when a trigger level is exceeded, certain high-VOC pesticides are prohibited.[39] California is the only state in the US that reports specifically on VOCs emissions associated with pesticides, but the estimates have their limitations, as information on ozone pollution due to pesticide formulation ingredients is limited.[40]

In an inventory of pesticide emissions from an agricultural area of China, emission factors for VOCs were highest for an orchard insecticide with beta-cypermethrin and malathion in an emulsifiable concentrate formulation. This formulation had a high (80%) content of "inactive"[1] ingredients, meaning it had a high content of organic solvents. In addition, it was found that when a pesticide adjuvant was in suspension, the VOC emission factor was low but contributed to a high $PM_{2.5}$ concentration. Time was also a factor in emissions, as pesticide applications intensified during the growing season, with herbicides found to be the largest contributor to VOC emissions. More information on solvents in formulations would improve the ability to measure emissions.[41] Based on the findings, emissions reductions could be achieved with measures taken around pesticide applications.[42] Inventories of pesticide emissions have also been discussed as a method for estimating a population's exposure to a pesticide.[43]

Reducing nitrous oxide and other GHG emissions by promoting healthy soils

Reducing N_2O emissions has been thought of as way to potentially reduce the effects of anthropogenic climate change in a shorter time frame than reducing CO_2.[44] N_2O is the third most important GHG, after carbon dioxide and methane.[45] N_2O is 310 times more potent than carbon dioxide and is a byproduct of the natural processes of nitrification and denitrification. In agriculture, the majority of N_2O release is due to fertilizer applications. Denitrification is the conversion of nitrate back to nitrogen gas, returning it to the atmosphere. Excess application of nitrogen fertilizer can increase nitrification, which can cause nitrate to leach into groundwater or surface water.[49]

There is also evidence that N_2O emissions from poorly draining soils have been underestimated in the US Corn Belt.[46] In addition, fumigant pesticide use increases N_2O emissions.[47] [48] As part of a comprehensive strategy on GHG emissions, reducing N_2O emissions in agriculture could provide co-benefits, such as recovery of the ozone layer, which prevents harmful UVB rays from reaching Earth. The ozone layer is not to be confused with ground level ozone, which is an air pollutant.[49]

Additional co-benefits arise from reducing agrochemical inputs. More sustainable soil management practices that reduce fertilizer applications have the added benefit of reducing nitrate contamination, which has adverse effects on water quality.[6] Nitrates in drinking water have adverse effects on infants and fetuses during pregnancy, as a major source of groundwater nitrate contamination comes from the intensive use of nitrogen fertilizers on crops.[50]

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[1] The study referred to "inactive" and "non-active" ingredients. It is not clear whether the terms have the same context as "inert" ingredients, a common term in the US. In the US, inert ingredients make up a significant portion of a pesticide formulation and would include solvents. Inert ingredients can also have biological activity, and US EPA has reported that over 500 inert ingredients have been used as active ingredients in other formulations. See Cox and Surgan, "Unidentified Inert Ingredients in Pesticides: Implications for Human and Environmental Health." *Environmental Health Perspectives* 114, no. 12 (2006): 1803–6. https://doi.org/10.1289/ehp.9374.

Building healthy soils will reduce reliance on synthetic nitrogen fertilizers, thus reducing N_2O emissions. In addition, GHG emissions can be generally reduced by reducing reliance on pesticides. The combination of pesticide use, low plant diversity, and the poor soils found in monoculture increase pest pressures. Agroecological principles focus on what makes a farm ecosystem vulnerable to pest pressures, and rely on strategies like biodiversity and healthy soils to manage the agroecosystem with low agrochemical use.[51]

Conservation measures that build healthy soils will help prevent soil erosion, which may in turn sequester soil carbon and enhance soil uptake of CH_4.[6] Complex crop rotations, cover cropping and organic soil amendments increase plant residues and soil microbial diversity, that in turn increase SOM, increase soil organic carbon, and mitigate GHG emissions.[52] [53] [54] These practices improve nutrient availability to plants and enhances natural disease suppression, reducing the need for fertilizer and pesticide inputs.[52]

Reducing greenhouse gas emissions through practice shifts in agriculture
Farming practices that reduce reliance on agrochemical inputs will reduce reliance on pesticides and other external inputs, and in turn will reduce GHG emissions.[55] Effective long-term measures to adapt the agricultural system to the changing climate will require agroecological strategies that favor crop and landscape diversity, increasing the productivity, sustainability, and resilience of agricultural systems. This approach to transforming agriculture will reduce the negative socioeconomic and environmental impacts that are expected with climate change.[56]

Call to Action

The recommendations from PAN's 2023 report have not shifted dramatically. The recent policy changes in the US indicate that meaningful progress in the US will be difficult in the coming years. [57] Research on climate change that generates new scientific findings should inform policies that mitigate GHG emissions — at least in individual US states and internationally. Governmental policies must address ways to mitigate GHG emissions because they threaten human health and well-being.

Transitioning our agricultural systems to those that uplift ecological and social justice principles will help mitigate climate change. In addition, such a transition would reduce the negative health impacts of industrial agriculture — for example, those that come from exposure to pesticide drift, to pesticide residues in food, or to air pollution from agrochemical use.[15] [58] [59] We can collectively support the advocacy work of impacted communities and organizations fighting for more equitable and sustainable food and farming systems right now.

Some proposed solutions are false ones. For example, precision agriculture promises to reduce the use of petroleum-derived pesticides and fertilizers by using computer-aided technologies to determine need and then more accurately apply agrochemicals. However, precision agriculture increases the power and control of agrochemical companies, many of which own the precision agriculture platforms and the data inputted by farmers.[60] 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. Further, false solutions like precision agriculture perpetuate the food system's reliance on proprietary technology and agrichemical mega corporations, keeping our food systems beholden to corporate interests rather than public health.

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