Ecological Alternatives
to Chlorpyrifos in Banana Production Systems
2024

Chlorpyrifos in banana production: current practices and hazards

Chlorpyrifos is considered a highly hazardous pesticide (HHP)[1], and its hazards to human and environmental health have resulted in its ban in over 40 countries, including Argentina, Chile, Colombia, the European Union, Thailand, Vietnam, and others (UNEP, 2023; UNEP, 2024). Yet many global industries still rely heavily on chlorpyrifos for pest management, including the banana industry.

Banana production with chlorpyrifos poses multiple threats to human and ecosystem health through the manner in which the insecticide is applied. Typically, fruit is bagged with plastic that has been impregnated with chlorpyrifos (Altabtabaee et al., 2016). In addition to the direct hazards of chlorpyrifos that occur through worker exposure and consumer contact with pesticide residue on the fruit, these bags may be recycled without treatment or left in fields, increasing the pathways of exposure to humans and the environment. However, these hazards can be prevented through alternative pest management methods, many of which have ecological co-benefits.

Human health effects, exposure, and vulnerable communities

Exposure to chlorpyrifos can cause acute as well as chronic health issues for adults, children, and fetuses. Acute effects include seizures, loss of consciousness, paralysis, and death if exposed to large amounts, and fatigue, salivation, intestinal issues, sweating, changes in heart rate, and dizziness at low amounts. Chronic effects particularly harm children. Prenatal exposure to very low levels of chlorpyrifos can adversely impact children's brain development, affecting working and reference memory (Colborn, 2006). Even very low levels of chlorpyrifos residues in cord blood can cause developmental neurotoxic effects in children (Rauh et al., 2006).

People can be exposed to chlorpyrifos by consuming food contaminated with residues, inhaling chlorpyrifos particles or exposed dust, or absorbing the chemical through contact with the skin (Risher & Navarro, 1997). Of bananas exported to the EU, 10% had chlorpyrifos residues (Vicaire & Lyssimachou, 2019). Since February 2020, the European Commission has defined the Maximum Residue Level (MRL) of chlorpyrifos as the lowest detectable amount (UNEP, 2023). Chlorpyrifos degrades rapidly in the environment, but can persist for long periods in small amounts.

Hazardous pesticides disproportionately cause poisonings in countries of the Global South. Southern and Southeast Asia—both regions with significant banana export industries—have among the highest incidences of poisonings (Boedeker et al., 2020). One study in Costa Rica found that more than half of Indigenous Ngäbe and Bribi children living near banana plantations with chlorpyrifos-impregnated bags had traces of chlorpyrifos at levels that threaten their health (van Wendel de Joode et al., 2012). Another study in Costa Rica found that banana plantation workers have increased risk of penile cancer, melanoma, cervical cancer, and leukemia, likely caused by pesticide exposure (Wesseling et al., 1996).

Banana bags impregnated with chlorpyrifos pose a dual threat to ecosystems and people. Typical practices for chlorpyrifos-treated bag use in commercial plantations involve bagging fruit when the flower emerges and replacing the bags 3–7 times per week until harvest, ultimately using 35–45 kg/ha/yr of chlorpyrifos (Polidoro et al., 2008; Vézina, 2020). Plantation workers have frequent exposure to chlorpyrifos, both in the field and in packing plants. Water sampled in canals flowing from packing plants and downstream has been found to contain maximum concentrations of chlorpyrifos, at levels that could cause acute toxicity (Castillo et al., 2000). The source of this chlorpyrifos is likely leached from chlorpyrifos-impregnated bags that are removed by workers in the plants (Castillo et al., 2000).

Credit: FARMCOOP

Non-chemical alternatives to chlorpyrifos include ecological pest management practices that produce high-quality bananas — often with valuable crops like cacao or coffee — while protecting rural community health, boosting local economies and food security, and building agroecosystem resilience.

1 Highly hazardous pesticides (HHPs) are pesticides that pose a significant threat to human and environmental health, as designated by international designated classification systems (Inter-Organization Programme for the Sound Management of Chemicals, 2014)

Banana workers are exposed to chlorpyrifos in the field and in packing plants. Workers experience increased risk of cancer, while children living near these plantations have significantly higher levels of chlorpyrifos in their bodies than children living near organic farms.

In Costa Rica, approximately 22.5 metric tons of chlorpyrifos and its degraded products are released to the environment annually in commercial banana and plantain production (Altabtabaee et al., 2016). Some countries, including Ecuador and Colombia, recycle chlorpyrifos-treated banana bags (Peñuela, 2022). In Ecuador, banana bags are considered non-hazardous waste by the government, allowing them to be recycled with other plastics without specified decontamination treatment (Cadena et al., 2021). Most chlorpyrifos degrades after 10 days, but without sufficient exposure to sunlight or water, chlorpyrifos can linger for long periods of time (Altabtabaee et al., 2016; Peñuela, 2022). This could result in increased human exposure to harmful residues when the plastic is recycled into children's toys and other materials (Peñuela, 2022).

Environmental effects

Chlorpyrifos is moderately to highly toxic to birds, honeybees, fish, and aquatic organisms (Nallapaneni & Pope, 2005; Wołejko et al., 2022). It is also semi-volatile, meaning that it readily leaves surfaces in vapor form when outdoor temperatures are high, as is common in tropical banana-growing climates. Chlorpyrifos has been detected in waterways surrounding banana plantations: in sediments of drainage channels near plantations and packing plants, in the mouth of a river along the Atlantic Coast of Costa Rica, and in sea cucumbers living in a coral reef in the Atlantic Ocean off the coast of Costa Rica (Castillo et al., 2009). Chlorpyrifos is particularly toxic to freshwater fish, aquatic invertebrates, and estuarine and marine organisms because it can bioaccumulate in their bodies (Extension Technology Network (EXTONET), 1996). Levels of chlorpyrifos found in water samples at or downstream from banana packing plants pose an ongoing chronic risk to aquatic organisms (Castillo et al., 2009). Pollution of waterways from chlorpyrifos used in banana plantations threatens the health of downstream ecosystems.

Chlorpyrifos from packing plants contaminates waterways, is highly toxic to fish and other aquatic organisms, and threatens the health of downstream ecosystems.

Chlorpyrifos can also damage soil microbial communities and can persist in soil for durations ranging from two weeks to a year (Extension Technology Network (EXTONET), 1996). The presence of organophosphates such as chlorpyrifos in soil can dramatically decrease the relative abundance of predominant microbial species (Kalia & Gosal, 2011). Its degraded product, chlorpyrifos oxon, has an acute toxicity to soil microorganisms that is 26 times that of chlorpyrifos itself (Wang et al., 2010; Wołejko et al., 2022). Soil microorganisms are crucial to nitrogen cycling processes, so these harmful impacts negatively affect plant health. Furthermore, banana bags are typically made of polyethylene, which when left in the field, can disintegrate into microplastics. Polyethylene microplastics can act as a pesticide accumulator, increasing the persistence of chlorpyrifos in soil (Ramos et al., 2015). Therefore, it is likely that chlorpyrifos-impregnated bags exacerbate the hazard of the pesticide to soil health by extending its half-life in soil.

Chlorpyrifos-treated plastic bag waste harms soil microorganisms critical in nitrogen cycling processes, weakening plant vigor and health.

Alternatives to chlorpyrifos use for pest control in bananas

Farmers may obtain a higher profit for bananas that are not cosmetically damaged, so pest management is important to their economic success (Polidoro et al., 2008). In pesticide-based banana production, chlorpyrifos is primarily used to control banana rust thrips (*Chaetanaphothrips signipennis; C. leeuweni; C. orchidii*), the banana weevil borer (*Cosmopolites sordidus*), and the banana scab moth (*Nacoleia octasema*) (Hort Innovation, 2020). Fortunately, many nonchemical alternatives to chlorpyrifos exist that can manage these pests successfully, while also enhancing agroecosystem resilience and protecting domestic food security, the health of workers, rural communities and ecosystems, and the banana export economy.

Integrated pest management (IPM) offers a variety of alternative approaches to conventional chemical control of pests. The more robust approaches to IPM focus on *long-term pest prevention* through ecological management practices such as biological control, cultivar selection, and habitat alteration (UC Statewide IPM Program, n.d.). Prevention is the most effective form of pest management, as it reduces the cost of external inputs as well as the negative human and environmental health impacts associated with chemical (or "reactive") pest control efforts (Porter, n.d.). By using ecological pest management practices that increase diversity in the cropping system and improve soil and plant health, farmers strengthen crop resilience to pest attacks and prevent many common pest problems from arising (Altieri, Nicholls et al., 2005).

Using only one management strategy for a pest, such as chemical control, increases the likelihood of a pest adapting to or evolving resistance to that one pest control method. In contrast, using multiple nonchemical IPM strategies increases the effectiveness of pest management and resilience of the cropping systems (Altieri, Nicholls et al., 2005). The following management strategies can be used to accomplish these goals.

Building healthy soil

The establishment of damaging pest populations can be prevented by enhancing plants' natural defense mechanisms. Banana plants have natural defense chemicals that release when herbivory occurs (Hölscher et al., 2016). These beneficial responses can be strengthened with healthy soil high in organic matter, which provides plants with the energy and nutrients necessary to create their own defense chemicals. Increasing soil organic matter through the addition of compost, green manure, animal manure, or other organic fertilizers increases plant resistance to and recovery from herbivory (Altieri, Ponti et al. 2005; Meyer, 2000).

Intercropping

Another well-known approach to pest prevention involves selecting for pest resistant cultivars and planting these cultivars together. The Cavendish cultivar is the only variety grown for the banana export industry, leading to a narrowing of genetic diversity in uniform monocropping systems and greater susceptibility to disease than in multi-cultivar cropping systems (Banana Link, 2020; Wolfe, 1985). A study in Uganda found that when multiple traditional banana cultivars are planted together, pest incidence decreases when compared with monocultural banana plantations (Mulumba et al., 2012).

Increasing diversity by intercropping with other plant species prevents pest proliferation by confusing potential pests and attracting predators of those pests (also known as "natural enemies"). Cropping systems with high plant diversity disrupt the ability of pests to find the crop, slowing their immigration into and movement through a crop (Stanton, 1983).

In Uganda, the practice of planting multiple traditional banana cultivars together increases crop genetic diversity and resilience against pest and disease damage, while providing nutritional and health benefits to the community.

Credit: Fernando Ramírez-Muñoz

In Costa Rica, organic farmers diversify their production by intercropping bananas with coffee or other profitable crops. These practices reduce pest damage, provide added income, and increase farming system resilience.

Biological control offers an effective alternative to hazardous pesticides. Banana pests such as weevils and thrips can be managed with entomopathogenic fungi such as Cordyceps and Beauveria species.

Bananas can be intercropped with other crops such as coffee, cacao, coconut, soursop, and moringa, that provide additional economic benefits (Bellamy, 2013; Claydon, 2021).

Cover cropping

Cover cropping is a management technique that not only can sustainably manage weeds, but also can promote ants, which are an effective natural enemy of the banana weevil. A study in the Caribbean found that the addition of a cover crop increases the population of weevil predator, *Solenopsis geminata*, leading to increased ant predation on weevil eggs (Mollot et al., 2012). In this study, signal grass (*Brachiaria decumbens*) and Bermuda grass (*Cynodon dactylon*) were used as cover crops, and both supported an increase in *S. geminata* abundance, compared to banana plantations with bare ground. The addition of these cover crops increased weevil predator density and resulted in a significant increase of predation on weevil eggs, with as much as 70% of weevil eggs removed by the ants.

Cover crops in banana plantations also help protect soil from erosion, enhance soil structure, increase soil biodiversity, reduce nutrient leaching, and increase organic matter, among other benefits (Vézina, 2018). Achard et al. (2018) investigated the effect of cover cropping with signal grass and Bermuda grass on Cavendish banana yield and productivity over two growing cycles. The study found that after the first cycle, banana growth was slower and the flowering date was delayed. However, after the second cycle, the banana canopy filled out and the mowed cover crop enhanced nutrient supply to banana plants. Both cover crops had no effect on final crop productivity nor the size and weight of the bananas in the second cycle compared to control banana plants (Achard et al., 2018). After banana canopies are established in the second growth cycle, cover cropping can enhance pest control naturally and build soil health while maintaining banana growth and yield, without dependence on expensive and hazardous insecticides.

Biological control

Research in recent years has found biological control methods for banana red rust thrips and banana weevils. Clercx et al. (2015) found that the fungus, *Isaria fumorosea,* is an effective bioinsecticide in both the lab and field for red rust thrips in Peru. Another study found that the parasitic wasp, *Megaphragma* sp., parasitized red rust thrips eggs up to 50%, while entomopathogenic fungi, *Beauveria (Cordyceps) bassiana* and *B. thuringiensis,* can cause 100% mortality in adult thrips (Arias de López et al., 2020).

Weevils can be controlled by entomopathogens as well. Negrete González et al. (2018) found that certain native isolates of *Cordyceps bassiana* and *Metarhizium anisopliae* caused adult mortalities of from 77–80% under laboratory conditions. Application of these same isolates in field trials in Mexico led to a reduction of weevil populations by 49%, and their combined application by 38.5%. The study identified entomopathogenic fungal isolates suitable for development and use in integrated pest management of the banana weevil. For the banana scab moth, ants such as *Tetramorium bicarinatum* can provide a low level of suppression (Pinese & Piper, 1994).

Pheromone trapping

Pheromone trapping has been proven as another effective alternative to chlorpyrifos for controlling banana weevils. Best practices are to use large (40x25 cm), brown ground traps with edges covered in soil, filled with dishwashing

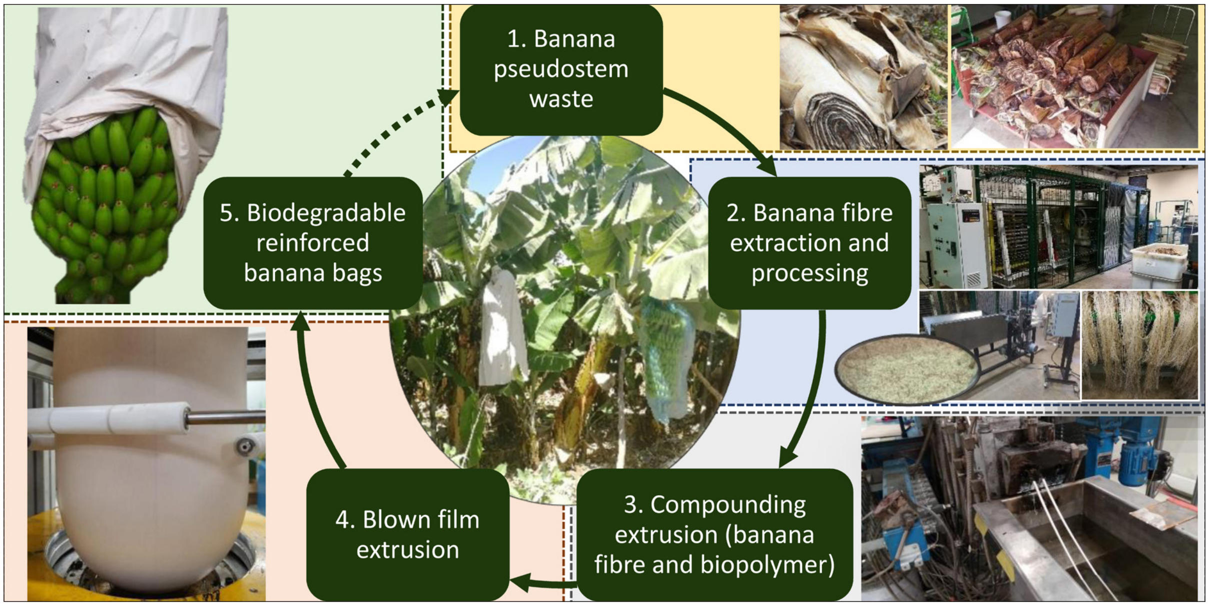

Fig. 1. Biodegradable bags made from banana stem waste offer a viable alternative to the dual hazards posed by chlorpyrifos-treated plastic bags (from Bordón et al., 2021).

liquid (1–3%) mixed with water, and a weevil-produced hormone to lure and trap large numbers of weevils (Reddy et al., 2009). The addition of pheromone trapping to conventional, pesticide-using systems can decrease corm damage by 61–64% and increase banana bunch weights by 23%. In Costa Rica, Martinique, Guadeloupe, and the Canary Islands, about 10% of banana growers already use pheromone trapping as a weevil control method (Alpizar et al., 2012). Commercial insecticide control results in an average of 20–30% of plants damaged by weevils, while the addition of an effective pheromone trapping in the conventional system reduces damage to <10% (Alpizar et al., 2012). This method could enhance weevil control alongside cover cropping techniques.

Bagging fruit without insecticides

Bags without insecticides are effective in protecting bananas from damage by banana red rust thrips. A study across multiple sites in Ecuador, Peru, and the Dominican Republic found that pesticide-free bags still reduced crop losses due to thrips to 0–5% compared to losses without bags, which ranged from 29–90%. The addition of bioinsecticides did not affect the losses, suggesting that bagging alone is the most effective non-insecticidal thrips control method. Bagging at the closed-bell stage, with bags replaced 2–3 times per week, was identified as best practice (Arias de López et al., 2020).

Biodegradable bags have been developed to replace plastic bags in the banana industry. Bordón et al. developed a protective biodegradable bag made of banana pseudostem waste that resulted in faster maturing fruit compared to conventional polyethylene bags. The transition to banana waste-derived biodegradable bags could increase local jobs and decrease reliance on imports and inputs for pesticide control (Bordón et al., 2021). Other manufacturers have developed biodegradable banana bags, such as BanaBag by the paper product manufacturing company Smurfit Kappa (*BanaBag*®, n.d.). Both bags meet the biodegradable requirements of EN13432 and have the potential to be an effective alternative to the coupled hazard of insecticide-treated plastic bags (Rosenheim et al., 2015).

Agroecological co-benefits of phasing out chlorpyrifos

Without the presence of chlorpyrifos and polyethylene in soil, there would likely be a higher diversity and abundance of microbial species, which can in turn increase nitrogen availability to plants (Kalia & Gosal, 2011; Wang et al., 2010). Enhancement of nitrogen cycling would decrease reliance on synthetic nitrogen inputs, increasing domestic food security, and decreasing greenhouse gas emissions associated with chemical fertilizer production and distribution.

Microplastics from banana bags have been found to decrease the abundance of beneficial natural enemies of pests: one study found that the presence of polyethylene microplastics in soil significantly decreases the abundance of ants, the natural enemy of banana weevils and banana scab moths (Lin et al., 2020). Eliminating the use of polyethylene banana bags would not only reduce microplastic environmental contamination but also enhance the pest control of banana weevils and banana scab moths by supporting a greater abundance of ants (Pinese & Piper, 1994). Furthermore, agroecological practices such as cover crops, crop rotation, and green manure have been found to increase farming system resilience to extreme weather events (Holt-Giménez, 2002). These methods have also enabled farmers to reduce or eliminate their use of harmful herbicides such as paraquat (Stuart et al., 2022).

Organic Banana Cooperatives in the Philippines

In the Philippines, the grassroots nonprofit organization Foundation for Agrarian Reform Cooperatives in Mindanao (FARMCOOP) supports small family farmer cooperatives, and helps transition small banana farms to non-chemical practices. These banana farmworkers have suffered many adverse health impacts from chemical pesticides supplied to them by banana exporting companies such as Dole.

FARMCOOP helped the Indigenous Bagobo-Tagabawa community establish organic banana farms, exporting high quality certified organic bananas and creating a secure local economy. When FARMCOOP became a part of the International Federation of Organic Agriculture Movements (IFOAM), they expanded their educational support programming and worked with Indigenous farmers to share traditional agricultural knowledge on water conservation and soil management, integrating this knowledge into production systems across Mindanao. They support small farms in agroecological farming approaches such as diversifying their banana systems to include cacao, fruits, and other native plants and trees and cover cropping to introduce nitrogen. FARMCOOP has helped many farmers move away from farming with hazardous chemicals and towards economically and environmentally sustainable farming.

More support is needed, however, to encourage agroecological practices in the Philippines. Although there is a market for organic exports, limited infrastructural support makes organic production difficult. Many plantations, in the absence of the involvement of large corporations, are without irrigation infrastructure. This prevents farmers from producing their own organic compost in the hot climate, and decreases system resilience under conditions of increasing climate variability. A challenge for banana production in the Bagobo-Tagabawa community has been lack of smooth roads, which creates a high amount of bruised fruit that is not accepted for export. By investing in farmer-led initiatives in agroecological banana production, expanding research, education and extension in agroecological farming, addressing infrastructural needs, and ensuring farmers have secure and sustained access to land, a thriving banana production model free of hazardous pesticides is possible.

(Apuzen-Ito, 2020a, 2020b; Bacon, 2020)

Credit: David Bacon

Organic banana cooperatives in Mindanao, Philippines have enabled farmers to stop using hazardous pesticides and export their produce on the international organic market. Here, Emilyn Jarolino, a Bagobo FARMCOOP staff member, describes the farm's successful conversion to agroecological approaches.

Credit: Fernando Ramirez-Muñoz

Policy recommendations

Increasingly, governments and international institutions are recognizing the need to take decisive action at the global level to end use of and reliance on highly hazardous pesticides, and replace them with non-chemical ecological approaches to pest management. Strong and enforceable regulatory frameworks are required to reverse the damaging effects of chemical-intensive agriculture on human health, rural communities, biodiversity, and the ecosystems on which life depends. This in turn requires national and global commitment to invest in and support transitions to agroecology.

The health, environmental, and ecosystem harms of chlorpyrifos are well-established. Government obligations to respect, protect, and fulfill the universal human right to health and to a clean, safe, and healthy environment demands swift action to eliminate chlorpyrifos from agricultural and residential use. A growing number of countries have already banned this neurotoxic insecticide, including the European Union, Canada, and Chile. A major retailer chain in Germany recently recalled corn products due to levels of chlorpyrifos residues detected above the legal maximum, highlighting the necessity for exporters to be able to ensure very low levels of chlorpyrifos residues on their bananas (*Deutschlandweiter Lidl-Rückruf*, 2023).

Fortunately, a wide array of non-chemical, ecological alternatives to chlorpyrifos exist that support effective pest management in banana production, while fostering human, ecological, and economic well-being. As more countries disallow chlorpyrifos residues on imported foods, the export market will expand for bananas grown using non-chemical ecological methods. Increasing support for these ecological approaches would ensure that a country's banana exports will meet an importing country's regulatory requirements.

Policy actions to enable the transition from chlorpyrifos-dependence to non-chemical ecological alternatives include:

- Phasing out and ultimately prohibiting all uses, production, sale, and export of chlorpyrifos by no later than 2030;
- Removing perverse incentives (such as government subsidies for chemical inputs) that favor continued dependence on hazardous inputs such as chlorpyrifos and establishing positive incentives that promote ecologically sustainable practices instead;
- Establishing systems for monitoring, recording, and evaluating national progress in reducing use of hazardous pesticides such as chlorpyrifos and their presence in the environment and as residues on produce;
- Building local and national capacity in agroecological research, extension, and innovation;
- Prioritizing participatory research and farmer-led innovation in ecological pest management in banana and other cropping systems;
- Providing financial supports that expand market opportunities and infrastructure access for organic producers, farmers adopting agroecological practices, and farmers "in transition" (including, for example, public procurement of local, organic, or ecological produce, establishment of participatory guarantee systems for ecological farmers, etc.); and
- Encouraging private investment in safe, sustainable, non-chemical approaches that reduce dependence on hazardous pesticides and plastics, protect biodiversity, and reduce greenhouse gas emissions.

Pesticide Action Network calls on national and global policymakers to:

➡ Phase out the use of highly hazardous pesticides in agriculture, as agreed under the United Nations *Global Framework on Chemicals*[2] and the *UN Environment Assembly Resolution on HHPs*[3];

➡ End double standards in the pesticides trade by prohibiting the manufacture and export of pesticides banned domestically; and

➡ Prioritize transitions to agroecology and the adoption of non-chemical, ecological approaches in pest management. These approaches build climate resilience, boost biodiversity, and protect people and the planet from harm.

Taking decisive action now to phase out HHPs and transition to agroecology will enable governments to address the triple planetary crisis of biodiversity loss, climate change, and pollution, while delivering on commitments agreed in key UN frameworks.[4]

2 See Target A7 of the Global Chemicals Framework, https://www.chemicalsframework.org/page/strategic-objectives-and-targets

3 See UNEA-6 Resolution 11, https://www.unep.org/environmentassembly/unea6/outcomes

4 See UNEA-6 Resolution 11, Targets A7 and D5 of the Global Chemicals Framework, and Targets 7 and 10 of the Kunming-Montreal Global Biodiversity Framework (https://www.cbd.int/gbf)

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Founded in 1982, Pesticide Action Network (PAN) International is a global network of grassroots and non-governmental organizations, institutions, and individuals that brings the voices, knowledge, and experiences of farmers, farmworkers, and rural populations together in advocating for food and climate justice around the globe. PAN International's network is coordinated by five PAN Regional Centers that collaborate to transform our local and global agrifood systems. PAN North America works to end reliance on hazardous pesticides, promote viable and vibrant solutions based in agroecology, and achieve health, resilience and justice in food and farming.

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