Chlorpyrifos:
Non-Chemical Alternatives

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Chlorpyrifos is an organophosphate insecticide used widely in agriculture. It is classified by WHO as Class II, moderately toxic. Humans are widely exposed through occupational use, contact with treated surfaces, ingestion or inhalation of contaminated dust, breathing air in treated buildings or near treated fields or orchards, contact with flea collars on pets, and residues in food and drinking water. It is a widespread contaminant of fruit and vegetables, cotton, coffee, rice and other grains and a range of food products.

Human health impacts

Detailed information on chlorpyrifos' health and environmental impacts can be found by referring to the Chlorpyrifos Monograph[1] prepared by Pesticide Action Network. Some key human health impacts are highlighted here which make the case for the need to find alternatives for chlorpyrifos.

Acute exposure to chlorpyrifos can cause increased secretions, sensory and behavioural disturbances, incoordination, depressed motor function, respiratory depression, tremors, convulsions, and death. Seizures lethargy, and coma are common in children.

Chlorpyrifos is an endocrine disruptor. It causes breast cancer cells to grow and is a breast cancer risk through its endocrine actions. In humans, defects of the brain, eyes, ears, palate, teeth, heart, feet, nipples, and genitalia have been associated with gestational exposure to chlorpyrifos. Chlorpyrifos exposure is associated with decreased birth weight and birth length, DNA damage in sperm, and decreased sperm concentration and sperm motility.

Chlorpyrifos is a potent developmental neurotoxin at low levels of exposure. Exposures *in utero* and in early childhood can lead to behavioural anomalies in adolescence and adulthood. Epidemiological studies have found delayed cognitive and psychomotor development, reduced IQ, attention-deficit/hyperactivity disorder (ADHD), and pervasive developmental disorder, smaller head circumference and altered brain structure.

There is evidence from laboratory and epidemiological studies of an association with Parkinson's disease.

In light of these human health impacts and environmental consequences, it is imperative that alternatives be found to the use of chlorpyrifos.

Alternative insecticides

There are many other synthetic chemical insecticides on the market, but most of these also have a range of adverse health and environmental effects, such as endocrine disruption, cancer, neurological damage, groundwater contamination, persistence, etc. Hence, their use is not recommended to replace chlorpyrifos.

Non-chemical[2] alternatives for chlorpyrifos

Ecosystem based approaches have been endorsed by various key international bodies such as the Food and Agriculture Organization (FAO)[3], the International Assessment of Agricultural Knowledge,

[1] Watts MA. 2013. Chlorpyrifos. Pesticide Action Network Asia and the Pacific, Penang. http://panap.net/en/p/page/pesticides/32

[2] The term non-chemical is used here to refer to substances and methods that are not synthetic pesticides, recognising that the borderline between some substances and synthetic pesticides is thin, and that some substances may be used as extracts from naturally occurring substances or as synthetic analogues – for example, neem, gibberllic acid, methyl eugenol, and pheromones. All of these substances were identified by countries and observers in the non-chemical category, and neem and pheromones at least are permitted in organic agriculture.

[3] Sustainable Intensification of Crop Production. Food and Agriculture Organisation of the United Nations. http://www.fao.org/ag/save-and-grow.

Science and Technology for Development (IAASTD)[4], the UN Special Rapporteur on the right to food[5], and the International Code of Conduct on the Distribution and Use of Pesticides[6].

Non-chemical alternatives that are effective in controlling crop pests while being safer than the use of synthetic insecticides should be employed. These could be the adoption of the use of least toxic naturally derived insecticides or an ecosystem-based approach to pest management.

Non-conventional substitutes for chlorpyrifos

There are some insecticides derived from natural plant extracts that can kill or repel insects; some deter insects feeding, or inhibit their growth. Natural soaps and minerals can also be used, as can naturally occurring pathogens like *Bacillus thuringiensis* (Bt) used as a spray—NOT as a genetically engineered part of the crop itself.

Care must be taken even with natural plant extracts as some, such as pyrethrum, can have toxic effects on beneficial insects, animals, and humans. Other plant extracts that can be used to replace chlorpyrifos include neem, lemon grass, garlic, ginger, marigold, quassia, turmeric, and many more.

Generally an insecticide, even a natural one, should be regarded as the choice of last resort, with the primary focus being placed on alternative pest management practices that prevent the need for a spray.

Ecosystem approaches to management of pests

These systems rely on ecosystem management rather than external inputs, with the first line of defence against pests being a healthy agroecosystem. They are knowledge-intensive, location-specific farming systems based on conservation practices, appropriate seed varieties, plant nutrition based on healthy soils, efficient water management, and the integration of crops, pastures, trees and livestock. The focus is on managing the agroecosystem to avoid build up of pests, using wherever possible cultural, biological, and mechanical methods instead of synthetic materials.

Such approaches have shown increased or similar yields, greater returns to farmers, and improvement in social and environmental indicators[7]. It is difficult to provide a simple prescription for a particular crop/pest complex in these systems as the entire interwoven management process is crucial to protecting crops from pests. Each crop/pest complex needs to be looked at within the specific agroecosystem, taking into account many aspects, including climatic and geographical variables, presence of natural enemies and availability of biological controls, the structure and function of the particular farm, and microclimatic variations within it.

Agroecological pest management focuses on sustainable ecological solutions that prevent pest build up. It takes a holistic approach to crop management that recognises pests as an integral part of the whole agroecosystem, forming a complex with beneficial insects, weeds, diseases and crops. The self-regulatory mechanisms of a highly biodiverse farming system help keep pest species in balance. A healthy soil with a rich diversity of biota and a high content of organic matter is key to sustainable management of pests and diseases.

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[4] IAASTD. 2009. Agriculture at the Crossroads. Synthesis Report. International Assessment of Agricultural Knowledge, Science and technology for Development (IAASTD). http://www.agassessment.org/.
[5] De Schutter O. 2011. Agroecology and the Right to Food. United Nations Special Rapporteur on the Right to Food. A/HRC/16/49. http://www.srfood.org/index.php/en/component/content/article/1174-report-agroecology-and-the-right-to-food.
[6] http://www.fao.org/agriculture/crops/core-themes/theme/pests/pm/code/list-guide/en/.
[7] UNEP. 2012. Evaluation of non-chemical alternatives to endosulfan. POPs Review Committee. UNEP/POPS/POPRC.8/INF/14/Rev.1.

Elements of alternative or ecological pest management

- Designing a farm ecosystem that encourages biodiversity, providing habitats for beneficial insects;
- Using resistant, often indigenous, crop varieties;
- Diversifying crops by intercropping, rotation, and use of multiple varieties;
- Cultural practices that encourage healthy soils and hence healthy plants, such as fallowing, appropriate tillage, water management, mulching, and use of animal manures, green manures, vermicasts, composts, liquid bio-fertilisers, and enhanced indigenous micro-organisms;
- Cultural practices that contribute to the suppression of pest populations, such as varying times of sowing, planting and harvesting, adjusting row width, use of trap crops, and appropriate pruning;
- Companion planting to deter pests;
- Accurate identification of both pests and beneficial insects and knowledge of their life cycles, habitats, and periods of population expansion and vulnerability;
- Enhancing the habitats and hence populations of (or introducing) natural enemies such as parasitoids like the *Encarsia* wasp and predators like the damselfly and spiders, as well as birds where appropriate; other beneficial insects that control pests for which chlorpyrifos is used include Braconid, *Cotesia* wasp, damsel bug, *Diadegma* wasp, carabid beetle, hoverfly, lacewing, ladybird beetles, minute pirate bug, praying mantis, predatory mites, rove beetles, spiders, tachinid flies, *Tiphia* wasp, and *Trichogramma* – see below for more details on some of these.
- Field sanitation, removing infested plant material including crop residues to reduce carryover of pests from one planting to the next;
- Systematic scouting of crops for pests and natural enemies, either regularly or at susceptible times, sometimes involving the use of sweep nets, sticky traps, and pheromone traps;
- Use of mechanical methods such as light traps, fruit fly traps, trenches (e.g. to prevent migration of rice molluscs into paddy fields), nets, reflective ribbon, bird perches, pheromone traps, sticky board traps, soil baits, soil traps, bagging of fruit, and plant ash; and
- Use of pheromone traps to trap insects and pheromone dispensers to disrupt mating. (SIBAT 1999a, 1999b; OISAT 2004; UNEP 2012)[8]

The Online Information Service for Pesticide Management in the Tropics (OISAT), established by PAN Germany, contains extensive information on managing particular pests in specific crops without the use of chlorpyrifos.

[8] SIBAT. 1999a. Keeping the Balance! Alternative Pest Management Training Manual for Vegetables. Sibol ng Agham at Teknolohiya (SIBAT); Rural Reconstruction Alumni and Friends Association (RRAFA); Centre for Environment, Technology and Development, Malaysia (CETDEM); Pesticide Action Network—Indonesia; Pesticide Action Network Asia and the Pacific (PAN AP). Quezon City, Philippines.

SIBAT. 1999b. Keeping the Balance! Alternative Pest Management Training Manual for Rice. Sibol ng Agham at Teknolohiya (SIBAT); Rural Reconstruction Alumni and Friends Association (RRAFA); Centre for Environment, Technology and Development, Malaysia (CETDEM); Pesticide Action Network—Indonesia; Pesticide Action Network Asia and the Pacific (PAN AP). Quezon City, Philippines.

OISAT. 2004. Online Information Service for Non-Chemical Pest Management in the Tropics. PAN Germany. http://www.oisat.org.

UNEP. 2012. Evaluation of non-chemical alternatives to endosulfan. POPs Review Committee. UNEP/POPS/POPRC.8/INF/14/Rev.1.

Some specific examples of biological controls[9]

1. Biological preparations

- *Neem/azadirachtin* - effective on over 200 pests including some species of whiteflies, thrips, leaf miners, caterpillars, aphids, scales, beetles, true bugs, and mealybugs; best used on immature stages of pests, before pest levels are high, and with repeated applications.

2. Pathogens

- *Bacillus thuringiensis*[10] Israeli - effective against mosquito larvae and is widely used as a larvicide in mosquito control programmes.
- *Bacillus thuringiensis* var *kurstaki* (Btk) - effective against larvae of members of the Lepidopteran family, i.e. moth and butterfly caterpillars, such as bollworms, leafminer, leafroller, diamondback moth, borers, budworms, army worm, cutworm, etc.
- *Beauveria bassiana*[11] – effective against aphids, boll weevil, stem weevil, caterpillars, codling moth, coffee berry borer, Colorado potato beetle, diamondback moth, European corn borer, fire ants, flies, grasshoppers, Japanese beetle, leafhoppers, leaf-feeding insects, mealybug, Mexican bean beetle, mites, psyllids (lygus bugs and chinch bugs), thrips, whiteflies, and some scales.
- *Metarhizium anisopliae*[12] - effective against aphids, thrips, leaf hopper, whiteflies, scarabs, weevils, mites, gnats, ticks, locusts, termites, cockroaches, flies, and mosquito larvae.
- *Nomuraea riley* - attacks the larvae of stem borers, leaf folders, army worms and case worms; also used against pod bore and cotton bollworm.
- *Helicoverpa armigera* nuclear polyhedrosis virus - against podborer, cotton bollworm, pink bollworm, fruit and shoot borer.

3. Predators

- *Chrysoperla carnea,* common green lacewing - the larvae prey on the nymphs and adults of aphids, bollworms, spider mites, jassids, thrips, whiteflies, leafhopper eggs, leaf miners, small caterpillars, beetle larvae, tobacco budworm, and others.
- *Coccinella septempunctata,* seven-spotted ladybird beetle - prey on aphids, whiteflies, and bollworms, attacking eggs, nymphs and adults; other ladybirds also prey on jassids, mealybugs, scale, mites, psyllids, timgids, planthoppers, and leafhoppers.
- *Orius* spp - thrips, spider mites, insect eggs, aphids, mites, psyllids, whiteflies, small caterpillars, corn earworm eggs, European corn borer, potato leafhopper nymphs, and leafminer.

4. Parasitoids

- *Trichogramma* sp - extremely tiny wasps that parasitize the eggs of hundreds of pests, including bollworms, borers, thrips, jassids, caterpillars, leaf miner, etc.
- Braconid wasps – parasitize larvae including aphids, beetles, bollworm, caterpillars, flies, and sawflies, etc.
- Ichneumonid wasps – parasitize larvae of diamondback moth, bollworm, caterpillars, pod borers, etc.

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[9] UNEP. 2012. Evaluation of non-chemical alternatives to endosulfan. POPs Review Committee. UNEP/POPS/POPRC.8/INF/14/Rev.1.
[10] *Bacillus thuringiensis* (Bt) is a naturally occurring bacteria used as a biological pesticide. There are a number of different strains that are active against different insect species.
[11] *Beauveria bassiana* is a naturally occurring entomopathogenic fungus, causing white muscadine disease in foliar pests through contact action.
[12] *Metarhizium anisopliae* is a widely distributed natural soil fungus that attacks a variety of insects, causing green muscadine disease.

Case example of non-chemical alternatives to the use of chlorpyrifos[13]:

Here we take the example of cotton to illustrate how it is possible to control pests most commonly found on cotton, using non-chemical methods instead of chlorpyrifos.
Cotton: The key pests on cotton addressed here are aphids, cotton bollworms and white flies.

Pest	Predators: Natural enemies introduced and encouraged.	Monitoring	Management and cultural practices	Curative control[14]
Aphids	Parasitoids like Braconid. Predators like Aphid midge, Damsel bug, Ground beetle, Hoverfly, Lacewing, Ladybird beetle, Rove beetle, Spider	Undersides of the leaves and the bud areas should be examined for groups or colonies of aphids. Prompt control is necessary as aphids can multiply rapidly	Grow different crops or grow crops in rotation every cropping season When transplanting, check carefully and use aphid-free seedlings Plant trap crops such as lupine, dill, nasturtiums, and timothy grass near the crop to be protected. Anise, chives, garlic, onions, and radish are also good companion crops. Control and kill ants. Plowing and flooding the field will destroy ant colonies and expose eggs and larvae to predators and sunlight. Ants use the aphids to gain access to nutrients from the plants. Avoid using heavy doses of highly soluble nitrogen fertilizers.	Apply extracts and preparations of the following plants: andographis, chilli, custard apple, eupatorium, finger euphorbia, ginger, gliricidia, mammey, neem, pongam, quassia, Spanish needle, sweet flag, turmeric, tomato, yam bean. Physical control of aphid infestations can be done by using water sprays, water traps, handpicking of aphids, pruning to reduce aphid infestation, use of sticky board traps
Cotton bollworm	Parasitoids like Braconid, Tachinid, Trichograma Predators like Damselfly, Hoverfly, Lacewing, Ladybird beetle, Minute pirate bug, Praying	Start bollworm monitoring after peak squaring (flower bud formation) and continue until most bolls have matured. To monitor, randomly choose 100 plants and look for larvae on the terminal	Practice crop rotation. Avoid planting crops successively that are susceptible to bollworm like cotton, corn, sorghum, tobacco, soybean, and tomato. In countries where there are 2 distinct seasons (wet and dry), during the rainy season plant rice followed by beans, cotton or small grains in the second	Apply extracts and preparations of the following plants: ginger, gliricidia, neem, tomoato Physical control can be done using pheromone traps, light traps, bird perches

[13] OISAT. 2004. Online Information Service for Non-Chemical Pest Management in the Tropics. PAN Germany. http://www.oisat.org.

[14] Actual preparation methods and application procedures can be found at PAN Germany's database OISAT (Online Information Service for Non-Chemical Pest Management in the Tropics) http://www.oisat.org/what_is_oisat.html

	mantis, Spider	growth. The treatment threshold is 10-12 small budworm or bollworm larvae for every 100 cotton plants	cropping. Grow a row of castor as border crop. Castor plants attract caterpillars that feed on cotton. Sow seeds of sunflower, black gram, and/or cowpea as trap crops in every 5 rows of cotton. These plants attract bollworm as well as provide habitat for natural enemies which feed on bollworms Burn cotton branches and debris heavily infested by bollworm. After harvest, plow-in plant residues immediately by incorporating these into the soil. Remove weeds surrounding fields when area is not planted with crops since these are the good laying sites for adults. Clear areas of weeds 2 weeks before planting.	
White flies	Parasitoids like Encarsia. Predators like lacewing, ladybird beetle, spider.	Look at the underside of the leaves to see the tiny eggs, larvae, and the adults. Shaking the plants gently would disturb the adult whiteflies and they will fly off. If there is an incidence of whitefly infestation, prompt control is necessary as whiteflies multiply their numbers rapidly	Do not plant cotton near other crops that have whitefly infestation. This could lead to early infestation and ruin the whole crop. Plant susceptible crops such as cotton at least one-half mile upwind from other whitefly host crops. To stop the whitefly lifecycle, plow the field immediately after harvest and incorporate the plant debris into the soil. Remove and destroy any whitefly infested plants. Plant Nicotiana, a flowering tobacco plant variety, as trap crop.	Apply extracts and preparations of the following plants: andrographis, chilli, garlic, ginger, gliricidia, guinea hen weed, neem onion, pongam. Physical control can be done using sticky board traps and growing seedlings under fine mesh nylon nets.