Insecticides: Environmental Fate and Toxicity

An initial recommendation: Be fair and cautious in what analogies you use to represent low concentrations ...

Mackay, D. 1988. On low, very low, and negligible concentrations. ***Environmental Toxicology and Chemistry*** 7: 1-3.

- Mackay notes that many people like to portray low concentrations of chemicals as negligible by using analogies that minimize ...
  - 1 ppm = 1 inch in 16 miles
  - 1 ppb = 2 seconds in a lifetime

- ...but if a cubic meter of a solid or liquid contains 10^{28} molecules...
  - 1 part per quadrillion = 10 billion molecules
  - Mackay referred to this as "the enormity of tinyness."

Concentrations to small to matter?

- A volume of soil 1 acre in area by 1-inch deep contains 3,120 cubic yards of topsoil.
- At 1 ton per cubic yard, this volume weighs 6,240,000 lbs.
- At an application rate of 0.14 lb a.i. per acre, a pyrethroid applied in a band along the row in corn at planting for soil insect control is present at 0.022 ppm in the top inch of the field as a whole and ~0.10 ppm in the top inch of the treated band … and it kills insects for a few weeks.

- Mackay also offered some more understandable analogies ... analogies that can be visualized:

- In a cubic meter of space:
- 1 ppm = a sugar cube
- 1 ppb = a broken pencil lead
- 1 ppt = a grain of salt

- Mackay argued that the significance of low concentrations depends on how the chemicals in question act in an organism.

- "Disruptives"... low concentrations may be negligible
- "Distributives"... partitioning among media make magnify concentrations
- "Directives" ... if the chemical damages DNA for example, a single or a few molecules at the "right" place might be enough to cause injury

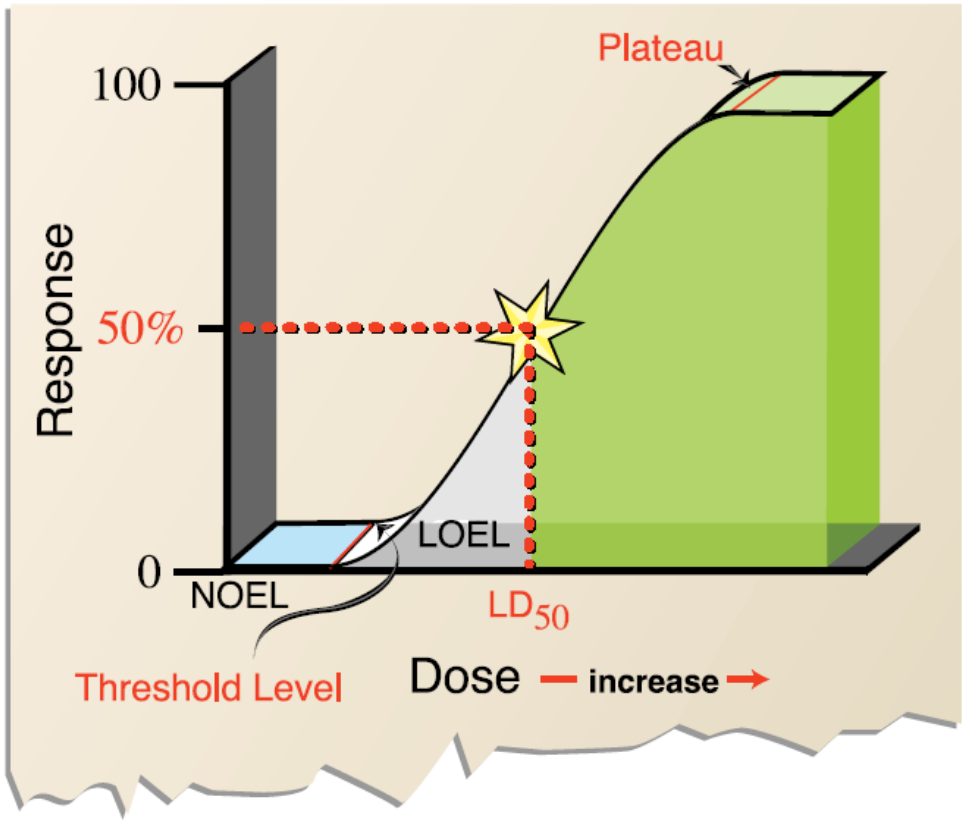
Why toxicology?

Read this.

- Pesticides are poisons, intentionally
  - They poison nontarget as well as target species because their modes of action are not specific to pest insects and not all insects are pests.
  - Humans, other mammals, fish, birds, and nontarget invertebrates (including natural enemies of pests) may be posioned.
- Lorenz, E.S. 2009. Potential Health Effects of Pesticides. http://pubs.cas.psu.edu/freepubs/pdfs/uo198.pdf. Covers …
  - Hazard = toxicity X exposure. Hazards are reduced by formulating low-concentration products and low-dust products; applying them to specific locations; requiring personal protective equipment (gloves, masks, etc.); imposing re-entry regulations and pre-harvest intervals (PHIs)
  - Toxicity may be viewed in different ways: acute vs. chronic; route of exposure (ingestion, inhalation, or dermal exposure); endpoint (skin or mucous membrane irritation, death, mutagenicity, carcinogenicity)

- Lorenz, continued
  - Signal words based on acute LD_{50}s…
    - Danger/Poison
    - Danger
    - Caution
  - Pesticide applicators are warned of symptoms of acute poisoning for insecticides, fungicides, and herbicides

Carbaryl (N-methyl carbamate)	Sevin	Malaise, muscle weakness, dizziness, sweating Headache, salivation, nausea, vomiting, abdominal pain, diarrhea Nervous system depression, pulmonary edema in serious cases
Chlorpyrifos (organophosphate)	Dursban	Headache, excessive salivation and tearing, muscle twitching, nausea, diarrhea Respiratory depression, seizures, loss of consciousness Pinpoint pupils
Endosulfan (organochlorine)	Thiodan	Itching, burning, tingling of skin Headache, dizziness, nausea, vomiting, lack of coordination, tremor, mental confusion Seizures, respiratory depression, coma
Malathion (organophosphate)	Cythion	Headache, excessive salivation and tearing, muscle twitching, nausea, diarrhea Respiratory depression, seizures, loss of consciousness Pinpoint pupils
Methyl Parathion (organophosphate)	Penncap-M	Headache, excessive salivation and tearing, muscle twitching, nausea, diarrhea Respiratory depression, seizures, loss of consciousness Pinpoint pupils
Phosmet (organophosphate)	Imidan	Headache, excessive salivation and tearing, muscle twitching, nausea, diarrhea Respiratory depression, seizures, loss of consciousness Pinpoint pupils
Pyrethrins (natural origin)		Irritating to skin and upper respiratory tract Contact dermatitis and allergic reactions—asthma
Pyrethroids (synthetic pyrethrin)	Cypermethrin, permethrin	Abnormal facial sensation, dizziness, salivation, headache, fatigue, vomiting, diarrhea Irritability to sounds or touch Seizures, numbness



A “rule” of toxicology often applied to the acute toxicity of substances is that “the dose makes the poison.” Studies that use laboratory animals are used to estimate the dose-response relationship for a pesticide, and one common outcome of such studies is the estimation of an LD_{50} – the dose (milligrams of toxicant per kilogram of body weight for the test animal) that killed 50 percent of the animals in the test and is likely to kill 50 percent of animals in a similar population.

Toxicity: the ability of a compound to cause injury or death

Mammalian Oral LD_{50} values for:

LD_{50} = dose that causes death to 50 percent of the animals to which it is administered in laboratory bioassays.

In general, the insecticides that have been developed after the organophosphates and carbamates have been less toxic to mammals.

Pesticide	mg/kg
DDT	113-118
chlordane	457-590
methyl parathion	14
chlorpyrifos	135-163
terbufos	2-5
malathion	885-2800
aldicarb	1
carbaryl	850
carbofuran	8-14
permethrin	430-4,000
rotenone	60-1500
nicotine	50-60
sabadilla	4,000
pyrethrins	1200-1500
microbials	NA

But what about long-term impacts of chronic exposures?

- Do pesticides cause other effects that may or may not be related to their primary mode of action as acute poisons?
  - Cancer?
  - Birth defects?
  - Endocrine effects?
- And how should testing for these effects be done?

References

Read this.

- Avery, Dennis. 1995. Saving the Planet Through Pesticides and Plastics. Hudson Institute, Indianapolis. (A biased and unscientific piece meant to arm the ill-informed with quotes instead of insights … "the gods' honest truth is it's not that simple." You can forego reading this … just understand that it's "out there.")
- Baier, C. 2000. Saving the Planet Through Pesticides and Plastics: A Critical Review. http://www.webpages.uidaho.edu/etox/resources/book_reviews/Planet.pdf
- Whitford, F., et al. 2003. Pesticide Toxicology: Evaluating Safety and Risk. http://www.extension.purdue.edu/extmedia/PPP/PPP-40.pdf (A description of how required toxicological testing of pesticides is done.)

- **Reasons for concerns about pesticides in environmental quality and human health result from a pesticide's:**

- persistence
- transport
- toxicity

If a pesticide is at all toxic to nontarget organisms, it's persistence (buildup over time) and its likelihood of movement to groundwater and surface water are important characteristics.

- **Persistence** is one determiner of the magnitude of residues in soil or on foods. Persistence can be represented by determining a pesticide's half-life. Half-lives in soil for a few organochlorine and organophosphate insecticides:
- DDT 3-10 yrs
- Heptachlor 7-12 yrs
- Chlordane 2-4 years
- Ethyl parathion 14 days
- Chlorpyrifos 30 – 90 days
- Diazinon 40 days

Ranking persistence (in a very general way):

- Longest
  - Inorganics such as lead arsenate
  - Chlorinated hydrocarbons
  - Neonicotinoids (some)
- Medium
  - Organophosphates
  - Carbamates
  - Pyrethroids
  - Neonicotinoids (some)
- Shortest
  - Botanicals
  - Soaps
  - Microbials

- **Rates of breakdown are dependent on:**
- concentration (extremely high concentrations degrade more slowly)
- temperature and moisture (increasing levels of either tend to speed breakdown)
- pH (organophosphates especially ... alkaline conditions speed hydrolysis, even in the spray tank)
- UV light speeds breakdown (especially for microbials)

- **Breakdown products (metabolites) can themselves be persistent & toxic:**
  - aldrin to dieldrin; heptachlor to heptachlor epoxide ... Metabolites are more persistent and more toxic
  - Alar (daminozide) to UDMH ... a carcinogen by current standards (apple story of 1980s)
  - aldicarb to aldicarb sulfoxide in watermelons & other cucurbits treated illegally (metabolite is more toxic than the original active ingredient) (watermelon story of 1990s)

Transport

- Residues may be carried away from application sites, often to unwanted destinations.
- Transport in/by water is influenced by persistence, water solubility, and soil sorption (K_{OC})

We will discuss how neonicotinoids compare with these in a later lecture.

Compound	Soil Half-life	K_{OC}	Water Sol. (ppm)
DDT	3-10 yrs	--	0.006
chlordane	2-4 yrs	--	0.1
parathion (methyl)	5 days	9800	57
chlorpyrifos (Lorsban)	30-90 days	4600	1
terbufos (Counter)	21-35 days	578	5
aldicarb (Temik)	70 days	28	6,000
carbofuran (Furadan)	30-90 days	45	320
carbaryl (Sevin)	10 days	230	40
permethrin (Pounce, Ambush)	30 days	10,600	0.04
esfenvalerate (Asana)	35 days	5,300	0.002
atrazine	60 days	100	33
alachlor	15 days	170	242

- In general, the values that trigger some concern about a pesticide's potential for environmental transport are a **half-life greater than 21 days**, a **soil sorption index of 300 to 500 (or less)**, and a **water solubility of greater than 30 ppm**. Triggering one or more of these concerns does NOT mean that a pesticide should not be used at all; it simply means that uses should be appropriate.

- So ... certain pesticides end up in ground water and surface water for specific reasons.
- Compounds most common in groundwater detections have been
  - old chlorinated compounds
  - Aldicarb (a carbamate sold under the trade name Temik)
  - nitrates
  - the herbicides atrazine, metolachlor, alachlor, and a few others.
  - Neonicotinoids – now and in the future??

- Reasons: persistence, volume of use, solubility, soil sorption.

- Low solubility / high soil sorption do not prevent surface water contamination
  - Pesticides attached to soil particles can be carried by erosive runoff (or by wind) and end up in water and aquatic organisms. Such problems are especially likely for preplant treatments applied to bare soil in the spring (rainy season).

- Risks of unwanted transport at mixing and loading sites (and toxic waste sites) are high for all compounds regardless of sorption, solubility, or normal persistence. High concentrations outweigh other characteristics. Some related issues to consider ...
  - Locations of ag chem facilities (and other point sources of various contaminants) in relation to community water wells
  - Location and construction of farm wells and mixing/loading practices
  - "Land-farming" to dispose of contaminated soils

Back to acute toxicity and LD_{50}s

- LOW numbers indicate GREATER toxicity!!
- LD_{50} values are not complete indicators even for acute toxicity.
- Toxicity is influenced by route of exposure, dilution, and combinations with other chemicals.
- Other types of injury (besides death) occur.
- Many individuals are more susceptible than average.
- Test animals may not accurately represent humans.

- OBVIOUSLY … Environmental toxicity is also an issue ... toxicity to fish (pyrethroids, rotenone, many others), bees (carbaryl, some neonicotinoids, many others), birds (DDT, Furadan), and plants (lead arsenate, others) are all concerns.

Chronic toxicity: Pesticides as carcinogens ... many have been identified

- Cancer tests use maximum tolerated doses (MTD's) as first screen. Does constant high dose cause different effects than what we should expect from occasional low doses? Are there threshold doses below which injury would not occur?
- Ames' bacterial mutagenicity test: Lots of positives among natural and synthetic compounds. Did this mean all those natural compounds really are carcinogens? (http://potency.berkeley.edu/pdfs/handbook.pesticide.toxicology.pdf)
- Data (relatively few) that exist from animal trials on the carcinogenicity of natural compounds show about the same percent positives as animal trials on synthetics. Do the samples (trials) represent the populations of compounds?

- **Possible conclusions:**
- Ames and others in this camp are wacko, wrong, paid off, or misdirected.
- Lots of compounds really are carcinogens. (And there's no need to add more synthetic ones.) OR (And the synthetic ones are negligible additions with useful roles.)
- The way we identify carcinogens is greatly flawed. (So what's a better way and what do we do until we improve the protocol?)

Erroneous logic:

- Humans evolved in the presence of natural compounds; they are therefore safer. (Consider that tests of carcinogenicity are done on rodents and that they too evolved in the presence of natural compounds). Also consider that cancer remains for the most part a disease associated primarily with aging ... how much impact on the evolution of a species?)
- All known human carcinogens also cause cancer in high-dose rodent studies, so all compounds that cause cancer in high-dose rodent trials must be human carcinogens.
- A ppb just isn't going to cause any effect.

- **Wiser Conclusions:**
  - Persistent pesticides have caused and continue to cause problems. We should not continue current uses or approve new compounds and use patterns to pose the excessive risks because of their presistence.
  - Transport in water, on soil, etc. moves compounds to unwanted sites; at these sites the pesticides pose health risks or may be more persistent. Challenge: to identify environmental transport risks of specific compounds and select chemicals and use patterns that minimize risks.
  - Most insecticides are broad-spectrum poisons that affect humans, other vertebrates, beneficial insects, etc. Challenge: to develop pesticides with selective toxicity.
  - We do not know the answers to all the questions about the risks posed by pesticides.