Soil health and pesticide effects

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The need for sustainable soil use (Wall & Six, 2015)

"We can't breathe, eat, drink, or be healthy without sustainably managing soils."

U.S. President Franklin D. Roosevelt (1937):
"A nation that destroys its soils destroys itself."

2015 International Year of Soils
healthy soils for a healthy life
PROTECT OUR SOILS

Effects of land-use intensification (Tsiafouli et al. 2015)

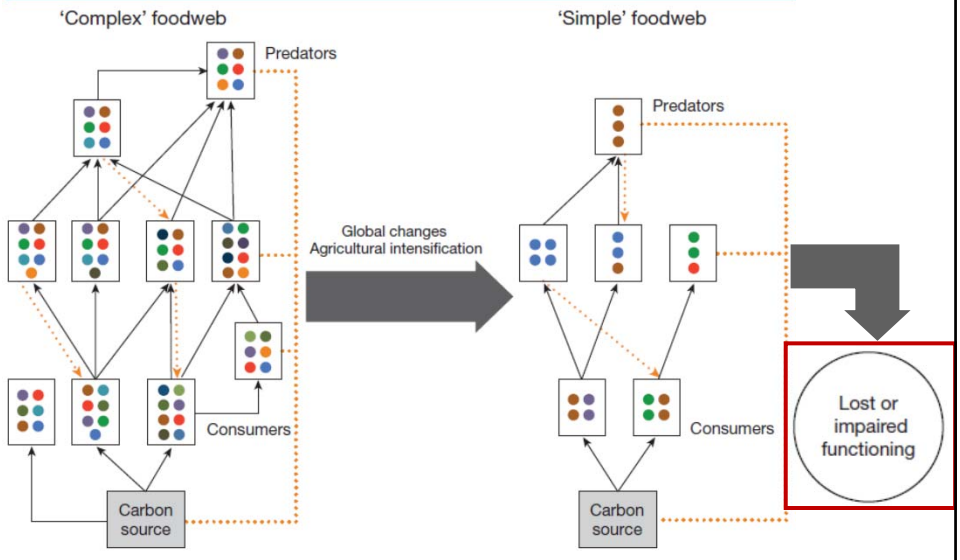
Increasing land-use intensity reduced

- complexity of soil food webs
- community-weighted mean body mass of soil fauna
- species richness of earthworms, Collembolans, oribatid mites
- etc.

Overall effects of land-use intensification:

- soil food webs less diverse, composed of smaller organisms.
- fewer functional groups of soil biota with fewer and taxonomically more closely related species

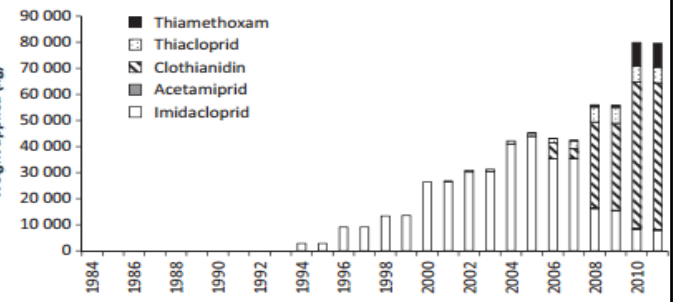
Key features in reduction of species in soil food webs - adverse effect on ecosystem functioning

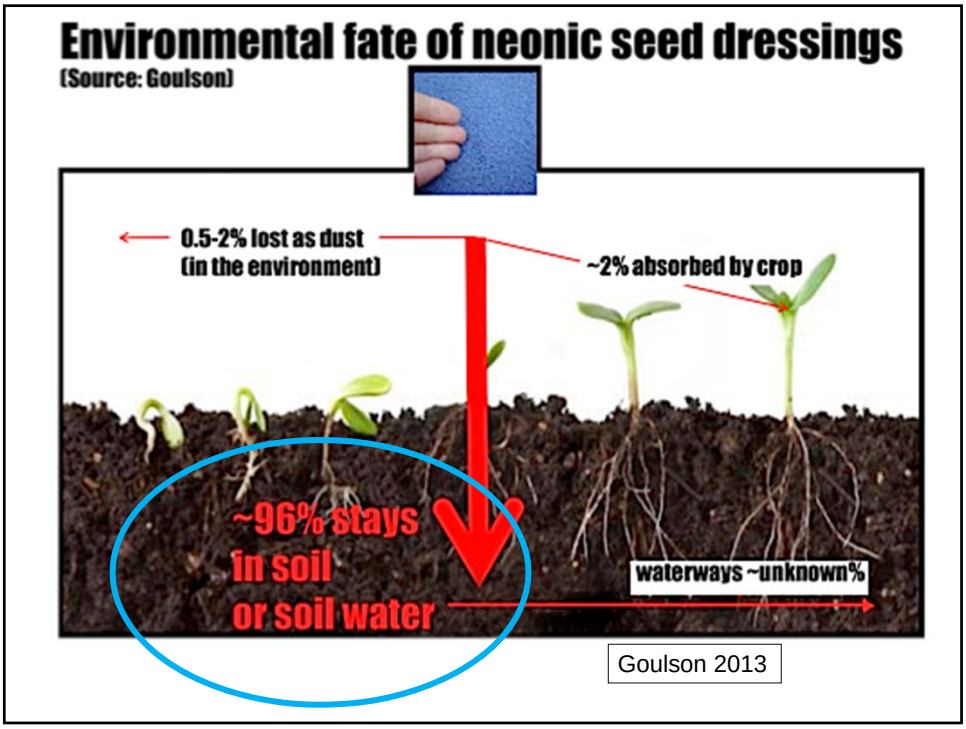


Wall et al., 2015

Neonicotinoids

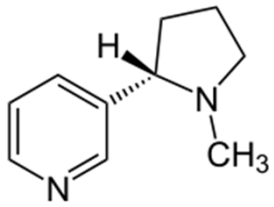
- Introduced as insecticides in 1990 (Kollmeyer *et al*. 1999)
- Agricultural use → seed dressing and foliar sprays (Goulson 2013)
- Systemic → whole plant is protected (Goulson 2013)
- Sunflower, maize, rape seed, cereals and potatoes (Goulson 2013)
- Application rates 30-150 g/ha (~0.03-0.15 mg/kg in top soil)





Origin/chemical properties

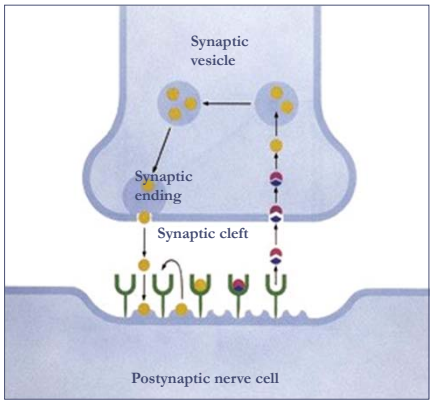
- Based on known action of nicotine as natural insecticide
- Nicotine is alkaloid acting on acetylcholine receptor



- 7 Neonicotinoids on the market;
- Two main chemical groups (nitro ←→ cyano substituted)

Mode of Action

- Bind irreversibly to nicotinic acetylcholine receptor on post-synaptic membrane
- Act as acetylcholine agonist → Paralysis or death



High receptor binding affinity:

→ Low-dose exposure over extended periods of time can culminate into substantial effects

→ Limits potential for recovery

Recent reviews on Neonicotinoids

(Introduced by Van der Sluijs et al., 2015)

- Persistent (for several compounds $T_{1/2}$ >> 100 days)
- Reasonably soluble in water → potential transport in soil
- Some metabolites also highly toxic

→ May accumulate upon repeated application

→ Widely distributed in environment

→ Concentrations in soil typically in µg/kg – mg/kg range

→ Often mixtures of active substances and metabolites

Recent reviews on Neonicotinoids

(Van der Sluijs et al., 2015; Pisa et al., 2015;Chagnon et al., 2015)

Knowledge gaps include e.g.:

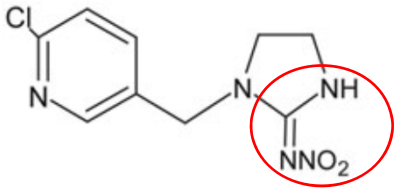
- Fate in soil
- Toxicity to soil organisms beyond earthworms
- Long-term effects
- Mixture toxicity
  - neonicotinoids and metabolites
  - Interaction with other types of pesticides
- Effects on ecosystem services in soil (due to effects on earthworms and springtails)

Two compounds; two chemical classes

Imidacloprid

- First (1991)
- >120 Countries; >140 crops.
- Highly toxic to honey bees and also for aquatic insects.
- EU ban from December 2013

N-nitroguanidines → nitro-substituted

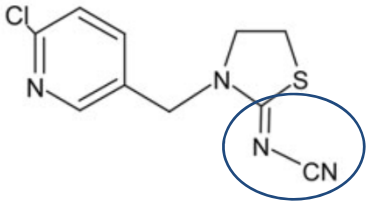


LD_{50} 0.018 **µg**/bee

Thiacloprid

- New type (2000)
- Agricultural crops, esp. pome fruits
- Same molecular mechanism but significantly different responses

N-cyano-amidines → cyano substituted.



LD_{50} 14.6 **µg**/bee

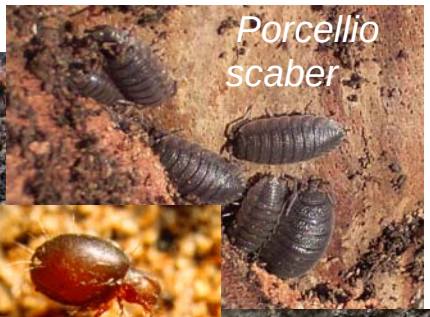
Iwasa et al. 2004

Research Questions - 1

Toxicity of neonicotinoids to different soil invertebrate species

1. How toxic are imidacloprid and thiacloprid to soil invertebrates?
2. Which soil invertebrate species are most sensitive to imidacloprid and thiacloprid?
2. Do imidacloprid and thiacloprid have similar toxicity to soil invertebrates?

Test organisms

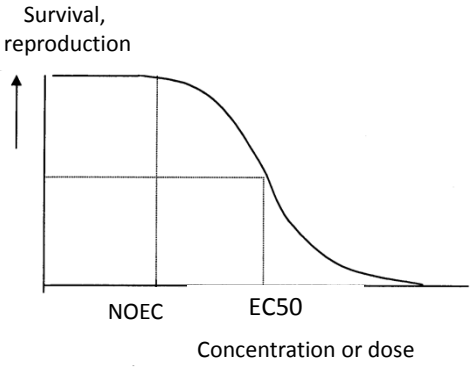


Methods - general

- LUFA 2.2 natural soil
- Treatments: range of insecticide concentrations in soil
- Controls
- Climate chamber; 20 °C, 16 hrs dark: 8 hrs light; 75% RH
- 21-28 days exposure
- Survival, reproduction (# juveniles), growth

Data analyses – dose-response

- Dose response models → LC_{50}, EC_{50}, etc.
  (Hamilton et al. 1977; Haanstra et al. 1985)



Summary of results

Species	**Imidacloprid** values mg/kg dry soil		**Thiacloprid** values mg/kg dry soil	
	LC_{50}	EC_{50}	LC_{50}	EC_{50}
F. candida 	0.20 – 0.64	0.10 – 0.26	2.7 – 3.9	1.7 – 2.4
E. andrei 	0.77	0.39	7.1	0.44
E. crypticus 	>30	2.0	>30	12
P. scaber 	7.6	6.7	>32	>32
O. nitens 	360	119	>1000	>100

De Lima e Silva et al. 2017

Research Questions - 2

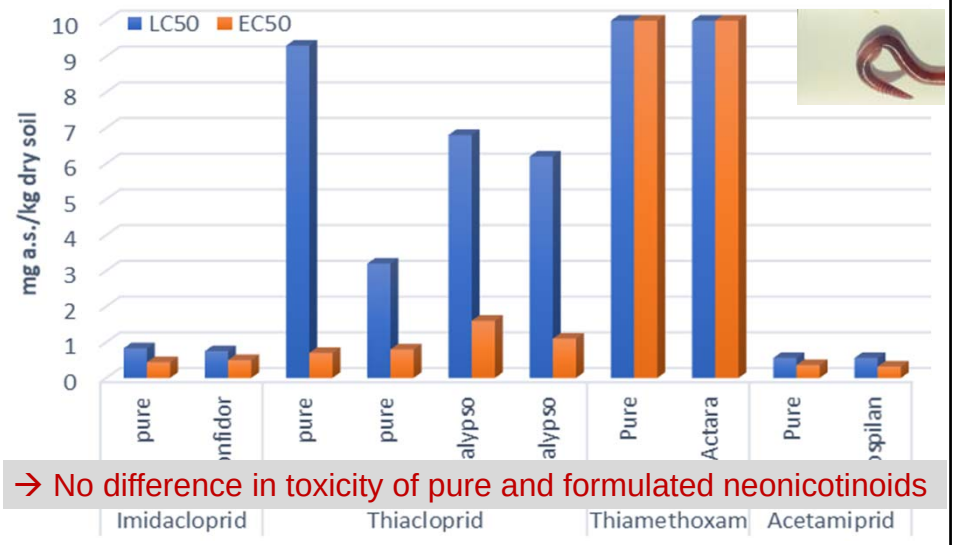
Starting points:

- All pesticides applied in commercial formulations
- Formulations contain several additives that might affect their efficacy, so also their toxicity

Question:

Are commercial formulations more (or less) toxic than pure active substances?

Toxicity of active substances ←→ formulations to earthworms *Eisenia andrei*



→ No difference in toxicity of pure and formulated neonicotinoids

De Lima e Silva et al. In prep

Research Questions - 3
Multi-generation toxicity testing

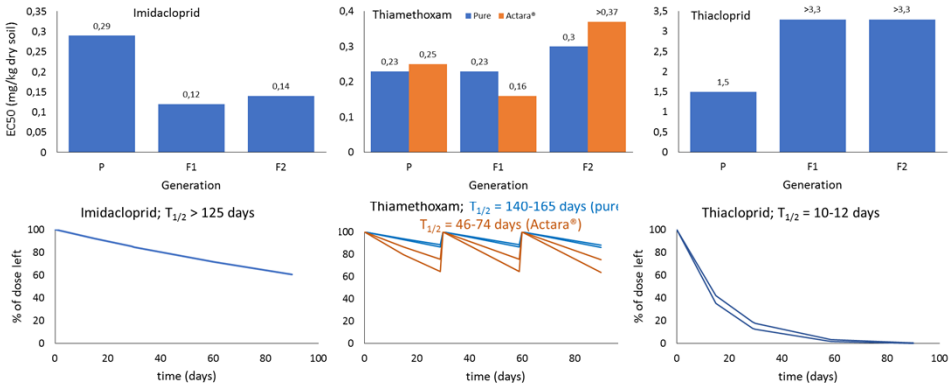
Starting points:

1. Springtails quite sensitive to neonicotinoids
2. Neonicotinoids bind irreversibly to acetyl choline receptor
   → cumulation of effects expected upon long-term exposure
3. Imidacloprid much more persistent than thiacloprid

Aims:

- Determining multi-generation effects of imidacloprid and thiacloprid to *Folsomia candida* in soil spiked once
- Multigeneration toxicity of thiamethoxam to *Folsomia candida* in repeatedly spiked soil

Multi-generation tests *Folsomia candida*



Imidacloprid quite stable: $T_{1/2}$ >125 days
Thiamethoxam repeated dosing + quite stable: $T_{1/2}$ 46-165 days
→ No toxicity change upon long-term incubation

Thiacloprid: decrease in toxicity after first generation
→ agrees with fast degradation ($T_{1/2}$ ~10-12 days)

Van Gestel et al. 2017; De Lima e Silva et al. In press

Answers to research questions

1. Toxicity of imidacloprid and thiacloprid to soil invertebrates?
   → Springtails (*Folsomia candida)* most sensitive
   → Earthworms (*Eisenia andrei)* also quite sensitive

2. Differences in the toxicity of imidacloprid and thiacloprid?
   → For survival in some cases considerable differences
   → Little difference for sub-lethal effects
      → Suggests difference in mode of action

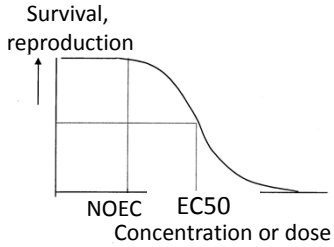
3. Toxicity of formulated products versus active substances?
   → No increased toxicity of compounds in formulation

4. Long-term toxicity?
   Toxicity of imidacloprid & thiamethoxam to springtails did not change upon long-term incubation; thiacloprid toxicity decreased due to fast degradation

Risk of neonicotinoids to soil invertebrates

General paradigm:

dose determines effect



Risk assessment

→ compare exposure and effect concentrations

Risk assessment of neonicotinoids to soil invertebrates

- Exposure: Predicted soil concentration (top 5 cm layer): 0.03-0.15 mg/kg
- Effect: EC_{50}s 0.10-0.44 mg/kg (springtails, earthworms)

→ Soil concentrations close to or above effect concentrations, already after single application

→ Potential risk to soil invertebrates of neonicotinoids studied

Conclusion – remaining questions

Neonicotinoids not only harmful for honey bees but also for soil invertebrates

- Several questions remain regarding
  - Exposure under field conditions?
  - Why difference in toxicity of imidacloprid and thiacloprid?
  - Role of toxicokinetics?
  - Difference in response of earthworms and enchytraeids?
  - How to explain high sensitivity of earthworms?
  - Possible ecosystem effects (biodiversity)?
  - Potential risk for soil ecosystem services?
  - Etc.

} Soil health

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