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Conclusions of the Worldwide Integrated Assessment on the risks of neonicotinoids and fipronil to biodiversity and ecosystem functioning

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Introduction

The use of systemic pesticides is increasing, including their use as a prophylactic. They are persistent and potent neurotoxins and concerns have been raised about their impacts on biodiversity, ecosystem functioning and the ecosystem services provided by a wide range of affected species and environments.

The combination of their widescale use and inherent properties, has resulted in widespread contamination of agricultural soils, freshwater resources, wetlands, non-target vegetation, estuarine and coastal marine systems. This means that many organisms inhabiting these habitats are being repeatedly and chronically exposed to effective concentrations of these insecticides.

Neonicotinoids and fipronil currently account for approximately one-third (in monetary terms) of the world insecticide market. They are used for insect pest management across hundreds of crops in agriculture, horticulture and forestry and are also widely used to control insect pests and disease vectors of companion animals, livestock and aquaculture, and for urban and household insect pest control and timber conservation.

The Worldwide Integrated Assessment (WIA) presents the first attempt to synthesize the state of knowledge on the risks to biodiversity and ecosystem functioning posed by the widespread global use of neonicotinoids and fipronil. It is based on the results of over 800 peer-reviewed journal articles published over the past two decades. The Authors assessed respectively the trends, uses, mode of action and metabolites (Simon-Delso et al. 2014), the environmental fate and exposure (Bonmatin et al. 2014), effects on non-target invertebrates (Pisa et al. 2014), direct and indirect effects on vertebrate wildlife (Gibbons et al. 2014), risks to ecosystem functioning and services (Chagnon et al. 2014) and finally explored sustainable pest management practices that can serve as alternatives to the use of neonicotinoids and fipronil (Furlan and Kreutzweiser 2014).

Mode of action, environmental fate and exposure

Neonicotinoids and fipronil operate by disrupting neural transmission in the central nervous system of organisms. Both pesticides produce lethal and a wide range of sublethal adverse impacts on invertebrates but also some vertebrates. Most notable is the very high affinity with which neonicotinoid insecticides agonistically bind to the nACh-receptor such that even low dose exposure over extended periods of time can culminate into substantial effects.

As a result of their extensive use, these substances are found in all environmental media including soil, water and air. Environmental contamination occurs via a number of disparate routes including: dust generated during drilling of dressed seeds; contamination and accumulation in arable soils and soil water; run-off into surface and ground waters; uptake of pesticides by non-target plants via their roots followed by translocation to pollen, nectar, guttation fluids, etc.; dust and spray drift deposition on leaves, and wind- and animal mediated dispersal of contaminated pollen and nectar from treated plants. Persistence in soils, waterways and non-target plants is variable but can be long; for example the half-lives of neonicotinoids in soils can exceed 1000 days and they can persist in woody plants for periods exceeding one year.

This combination of persistence (over months or years) and solubility in water has led to large-scale contamination of, and the potential for build-up in, soils and sediments (ppb-ppm range), waterways (ground water and surface water in the ppt-ppb range) and treated and non-treated vegetation (ppb-ppm range).

There is strong evidence that soils, waterways and plants in agricultural and urban environments and draining areas are contaminated with highly variable environmental concentrations of mixtures of neonicotinoids or fipronil, and their metabolites.

There are multiple routes for chronic and multiple acute exposure of non-target organisms. For example, pollinators (including bees) are exposed through at least: direct contact with dust during drilling; consumption of pollen, nectar, guttation drops, extra-floral nectaries, and honeydew from seed-treated crops; water; consumption of contaminated pollen and nectar from wild flowers and trees growing near treated crops or contaminated water bodies. Studies of food stores in honeybee colonies from a range of environments worldwide demonstrate that colonies are routinely and chronically exposed to neonicotinoids, fipronil and their metabolites (generally in the 1-100 ppb range), often in combination with other pesticides some of which are known to act synergistically with neonicotinoids.

Impacts on non-target organisms

Impacts of systemic pesticides on pollinators are of particular concern. In bees, field-realistic exposures in controlled settings have been shown to adversely affect individual navigation, learning, food collection, longevity, resistance to disease and fecundity. For bumblebees, colony-level effects have been clearly demonstrated, with exposed colonies growing more slowly and producing significantly fewer queens.

For almost all insects, the toxicity of these insecticides is very high including many species that are important in biological control of pests. The sensitivity to the toxic effect is less clear with non-insect species. For annelids such as earthworms, the LC_{50} is in the lower parts per billion range for many neonicotinoids.

At field realistic environmental concentrations, neonicotinoids and fipronil can have negative effects on physiology and survival for a wide range of non-target invertebrates in terrestrial, aquatic, wetland, marine and benthic habitats. Effects are predominantly reported from laboratory toxicity testing, using a limited number of test-species. Such tests typically examine only lethal effects over short time frames (i.e. 48 or 96 hour tests), whereas ecologically relevant sublethal effects such as impairment of flight, navigation or foraging ability, and growth are less frequently described. It has become clear that many of the tests use insensitive test species (e.g. *Daphnia magna*), and are not sufficiently long to represent chronic exposure, and therefore lack environmental relevance.

Our review shows a growing body of published evidence that these systemic insecticides pose serious risk of harm to a broad range of non-target invertebrate taxa often below the expected environmental concentrations. As a result an impact on the many food chains they support is expected.

We reviewed nearly 150 studies of the direct (toxic) and indirect (e.g. food chain) effects of fipronil and the neonicotinoids imidacloprid and clothianidin on vertebrate wildlife - mammals, birds, fish, amphibians and reptiles. Overall, at concentrations relevant to field exposure scenarios in fields sown with coated seeds, imidacloprid and clothianidin pose risks to small birds, and ingestion of even a few treated seeds could cause mortality or reproductive impairment to sensitive bird species. Some recorded environmental concentrations of fipronil have been sufficiently high to potentially harm fish. All three insecticides exert sublethal effects, ranging from genotoxic and cytotoxic effects, to impaired immune function, reduced growth, or reduced reproductive success. Furthermore, these effects often occur at concentrations well below those associated with direct mortality. This is a trend in many taxa reported throughout the reviewed literature: short-term survival is not a relevant predictor of mortality measured over the long term, nor of impairment of ecosystem functions and services performed by the impacted organisms.

Despite the lack of research and the difficulty in assigning causation, indirect effects may be as important as direct toxic effects on vertebrates, and possibly more important.

Indirect effects are rarely considered in risk assessment processes and there is a paucity of data, despite the potential to exert population-level effects.

Impacts on ecosystem functioning and ecosystem services

Neonicotinoid insecticides and fipronil are frequently detected in environmental media (soil, water, air) at locations where no pest management benefit is provided or expected. Yet these media provide essential resources to support biodiversity, and are known to be threatened by long term or repeated contamination. The literature synthesized in this integrated assessment demonstrates the large scale bioavailability of these insecticides in the global environment at levels that are known to cause lethal and sublethal effects on a wide range of terrestrial (including soil) and aquatic microorganisms, invertebrates and vertebrates. Population level impacts have been demonstrated to be likely at observed environmental concentrations in the field for insect pollinators, soil invertebrates and aquatic invertebrates. There is a growing body of evidence that these effects pose risks to ecosystem functioning, resilience, and the services and functions provided by terrestrial and aquatic ecosystems. Such services and functions can be provisioning, regulating, cultural or supporting, and include amongst others: soil formation, soil quality, nutrient cycling, waste treatment and remediation, pollination, food web support, water purification, pest and disease regulation, seed dispersal, herbivory and weed control, food provision (including fish), aesthetics and recreation.

Knowledge gaps

While this assessment is based on a growing body of published evidence, some knowledge gaps remain. These compounds have been subject to regulatory safety tests in a number of countries. However, several potential risks associated with the present global scale of use are still poorly understood.

For most countries there are few or no publicly available data sources on the quantities of systemic pesticides being applied, nor on the locations. Reliable data on the amounts used is a necessary condition for realistic assessments of ecological impacts and risks.

Screening of neonicotinoid and fipronil residues in environmental media is extremely limited despite their known water solubility and propensity for movement. Only very scarce data for marine systems exist.

Long-term toxicity to most susceptible organisms has not been investigated. For instance: toxicity tests have only been carried out on four of the approximately 25,000 globally known species of bees, and there are very few studies of toxicity to other pollinator groups such as hoverflies or butterflies and moths. Similarly, soil organisms (beyond earthworms) have received little attention, despite playing multiple roles in the formation and maintenance of soil fertility. Toxicity to vertebrates (such as granivorous mammals and birds which are likely to consume treated seeds) has only been examined in a handful of species.

Those toxicological studies that have been performed are predominantly focused on acute toxicity tests, whereas the effects of long-term, acute and chronic exposure is less well known, despite being the most environmentally relevant scenario for all organisms in agricultural and aquatic environments.

At present, no studies have addressed the additive or synergistic effects of simultaneous exposure to multiple compounds of the neonicotinoid family. Risk assessments are done for each chemical separately, while many non-target species, such as pollinators, are simultaneously being exposed to multiple neonicotinoids as well as other pesticides and stressors. As a consequence, the risks have been systematically underestimated.

Interactions between systemic insecticides and other stressors, such as other pesticides, disease, and food stress, have been explored in only a handful of studies but these have revealed important synergistic effects. For example, in honeybees, low doses of neonicotinoids greatly increase susceptibility to viral diseases.

Impacts of these systemic insecticides on the delivery of a wide range of ecosystem services are still uncertain. The accumulation in soil and sediments might lead us to predict impacts on soil fauna such as earthworms and springtails (Collembola), which may in turn have consequences for soil health, soil structure and permeability, and nutrient cycling. Contamination of field margin vegetation via dust, or ground or surface water might lead us to expect impacts on fauna valued for aesthetic reasons (e.g. butterflies), and is likely to impact populations of important beneficial insects that deliver pollination or pest control services (e.g. hoverflies, predatory beetles). General depletion of farmland and aquatic insect populations is likely to impact insectivorous species such as birds and bats. Contamination of freshwater is hypothesized to reduce invertebrate food for fish, and so impact fisheries. The same might apply to coastal marine systems, potentially posing serious threats to coral reefs and saltmarsh estuaries. None of these scenarios have been investigated.

The short- and the long-term agronomic benefits provided by neonicotinoids and fipronil are unclear. Given their use rates, the low numbers of published studies evaluating their benefit for yield or their cost-effectiveness is striking, and some recent studies suggest that their use provides no net gain or even a net economic loss on some crops. It is not currently known what the impact on farming would be if these systemic pesticides were not applied or applied less (though their recent partial withdrawal in the EU provides an opportunity for this to be examined).

Given these knowledge gaps, it is impossible to properly evaluate the full extent of risks associated with the ongoing use of systemic insecticides, but the evidence reviewed in the WIA suggests that while the risks affect many taxa, the benefits have not been clearly demonstrated in the cropping systems where these compounds are most intensively used.

Overall Conclusion

The existing literature clearly shows that present day levels of pollution with neonicotinoids and fipronil caused by authorized uses, frequently exceed lowest observed adverse effect concentrations for a wide range of non-target species and are thus likely to have wide ranging negative biological and ecological impacts.

The combination of prophylactic use, persistence, mobility, systemic properties and chronic toxicity is predicted to result in substantial impacts on biodiversity and ecosystem functioning.

The body of evidence reviewed indicates that the present scale of use of neonicotinoids and fipronil is not a sustainable pest management approach and compromises the actions of numerous stakeholders in maintaining and supporting biodiversity and subsequently the ecological functions and services the diverse organisms perform.

In modern agricultural settings, it is increasingly clear that insecticide treatments with neonicotinoids and fipronil - and most prominently its prophylactic applications - are incompatible with the original mindset that led to the development of the principles of integrated pest management (IPM). Although IPM approaches have always included insecticide tools, there are other approaches that can be effectively incorporated with IPM giving chemicals the position of last resort in the chain of preferred options that need be applied first. The current practice of seed treatment is the opposite: it applies chemicals as the first resort.

Because of the persistent and systemic nature of fipronil and neonicotinoids (and the legacy effects and environmental loading that come with these properties), these compounds are incompatible with IPM.

Recommendations

The authors suggest that regulatory agencies consider applying the principles of prevention and precaution to further tighten regulations on neonicotinoids and fipronil, and consider formulating plans for a substantial reduction of the global scale of use.

Continued research into alternatives is warranted, but equally pressing is the need for education for farmers and other practitioners, and the need for policies and regulations to encourage the adoption of alternate agricultural strategies to manage pests.

The adequacy of the regulatory process in multiple countries for pesticide approval must be closely considered and be cognizant of past errors. For example, other organochloride insecticides such as DDT were used all over the world before their persistence, bioaccumulation and disruptive impacts on ecosystem functioning were recognized, and they were subsequently banned in most countries.

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