Pesticide dosing must be guided by ecological principles

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Pesticide dosing must be guided by ecological principles

Insecticide use could be reduced if dose recommendations move from a toxicological perspective (how much is needed to kill an insect pest) to an ecological perspective (how much is needed to protect a crop).

Théotime Colin, Coline Monchanin, Mathieu Lihoreau and Andrew B. Barron

Insect populations are in sharp decline, with potentially catastrophic consequences for ecosystem function[1]. This is a complex problem, but the widespread use of pesticides is certainly part of it[2,3]. Debates continue about whether some insecticides should be banned, but where bans have happened different insecticides have been substituted. These may be no less harmful to insects[4]. Agriculture needs to move away from such a heavy reliance on pesticides and adopt an integrated pest management (IPM) approach[5] and a better regulatory process[6], but this change will take time with the IPM approaches proposed to date. Here we argue that we could immediately reduce the amounts of insecticide applied to the environment without necessarily risking loss of crop yields if we rethink pesticide dosing recommendations based on ecological principles. This action alone will not solve the pesticide problem, but will reduce pesticide pollution to win time while we transition to a more sustainable agricultural model.

Since 1990 the amount (measured in weight) of insecticide applied to farmland in the United Kingdom has actually decreased, but this is because modern insecticides are far more toxic than older options[7]. For example, neonicotinoids are 10,000 times more toxic to insects than even dichlorodiphenyltrichloroethane (DDT)[8]! In the United Kingdom, the land area treated with insecticides has increased sharply since 2000, and the frequency and diversity of insecticide treatments has also increased[9]. Therefore, in recent decades the toxicity of the environment in the United Kingdom to insects has increased.

The justifications given by any pesticide supplier for their dose recommendations are seldom clear. The research performed to justify the dose is proprietorial and not in the public sphere[6], which is itself a problem. Usually dose guidelines, when given, refer to a measure of the LD_{50} (the dose lethal to 50%) of the active ingredient(s) of the pesticide against the target, and pesticides are recommended to be used at doses causing a fast death in the targeted pests (Table 1). We argue this kind of effect is not needed to control damage to crops from insect pests.

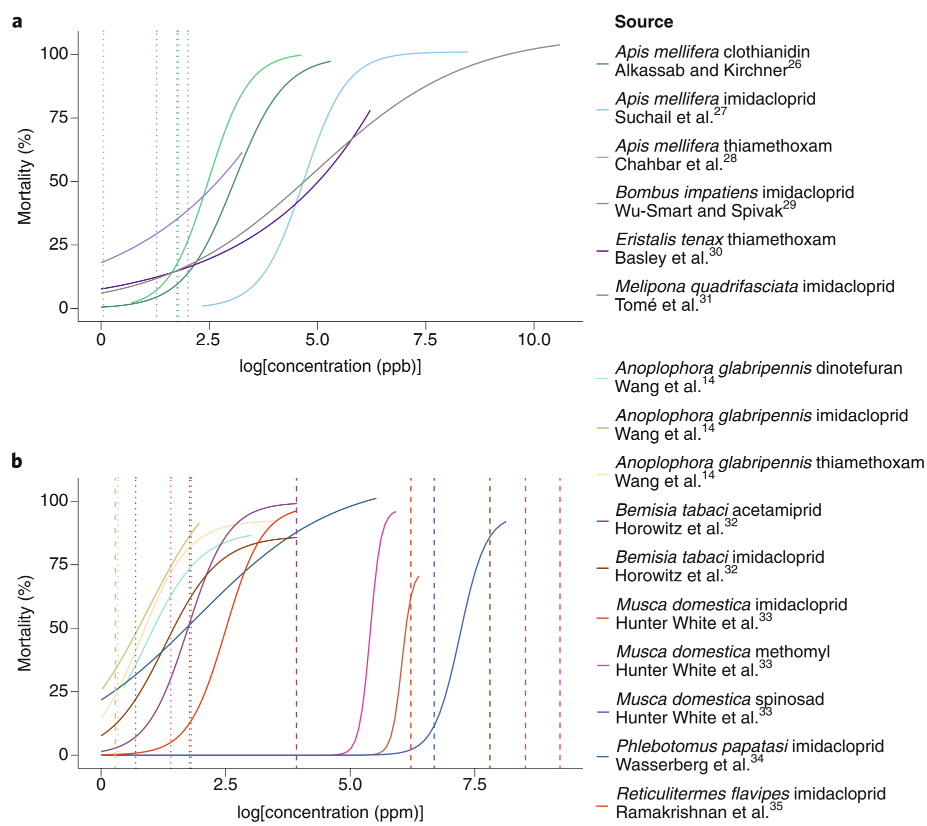

Fig. 1 | Examples of dose–response mortality curves for insects. a,**b**, Non-target (**a**) and target (**b**) insects[14,26–35]. Concentration is shown on a log scale. Colours represent different insect–insecticide combinations. Sublethal effects with impact on fitness (dotted lines) are often detected at doses well below the concentrations killing 50% or 100% of the population. Recommended doses for target insects (dashed lines, see Supplementary Methods) often exceed concentrations known to cause 100% mortality. Non-target insects are often more sensitive than targeted pests to insecticides[36], so concentrations are shown in parts per billion for non-target insects (**a**) and parts per million for target insects (**b**).

Currently, insecticides are applied at concentrations in the upper range of the mortality dose–response curve (Fig. 1, dashed lines) to deliver a rapid and total elimination of the pest. Mortality dose–response relationships are sigmoid[10]. As a consequence, a dose that yields even 90% mortality of the target organism can be far less than a dose yielding a promise of 100% mortality. For example, in the case of the cotton whitefly (*Bemisia tabaci*, Fig. 1b), a target of 90% mortality would reduce pesticide amount used by 75% from the current dose recommendation.

Table 1 | Research performed to justify the dose is mostly proprietorial, but usage guidelines for popular insecticides promise rapid eradication of pests

Manufacturer	Pesticide	Group	Marketed effect on pest
BASF	Dinotefuran	Neonicotinoid	"Control pyrethroid-resistant pests quickly"
Bayer	Spirotetramat	Keto-enol	"Suppression of woolly apple aphids", figure shows 80–100 "% control"
Bayer	Thiacloprid	Neonicotinoid	"Suppression of woolly apple aphids", figure shows 100% mortality
Corteva	Spinetoram and methoxyfenozide	Spinosyn, diacylhydrazine	"Faster knockdown and consistent control"
Corteva	Spinetoram and sulfoxaflor	Spinosyn, sulfoximine	"For control or suppression of listed pests"
Corteva	Chlorpyrifos and Lambda-cyhalothrin	Organophosphate, pyrethroid	"Fast knockdown and excellent residual control of a broad spectrum of insects"
Syngenta	Emamectin	Avermectin	Figures show 90 "% control" of a moth, and 100% bee mortality three hours after application
Syngenta	Pymetrozine	Pyridine	"Excellent control of aphid and suppression of whitefly populations"
Syngenta	Thiamethoxam	Neonicotinoid	"Death occurs by starvation within 24 hours"
Syngenta	Chlorantraniliprole and Abamectin	Ryanoid, avermectin	"Feeding stops within minutes, larvae start to wriggle then become paralysed, death follows after 48 hours"

See Supplementary Methods for references.

Sublethal effects of insecticides can be sufficient to eliminate economic damage to crops

Target insect pests may not need to be killed outright to prevent economic crop damage. Pesticides also have sublethal effects at low doses (Fig. 1), which can affect the feeding, vision, mobility, orientation, learning and fertility of insects[11]. These sublethal effects are known to severely reduce populations of beneficial insects[12,13], but they have been largely overlooked for the control of targeted pest insects.

There are examples of sublethal effects of commercial insecticides being sufficient to control target pest insects. Trees can be injected with highly concentrated doses of neonicotinoids to protect them against insect herbivores. Even when the insecticide doses injected into the trunks are highly concentrated, only sublethal concentrations end up in the leaves and twigs[14,15] (see purple dashed line in Fig. 1b for levels found in trees). These sublethal doses have nonetheless been shown to provide effective control against the Asian longhorn beetle[15] at doses 17 times less than the 100% lethal dose[14]. Two common insecticides, at sublethal doses, were found to cause the silverleaf whitefly to stop feeding and lay 75% fewer eggs[16], and tefluthrin inhibits feeding in the corn rootworm at a concentration causing only 20% direct mortality[17].

It is not necessary to kill all target insects to eliminate a pest population. The IPM paradigm has argued for decades that it is not necessary to treat a crop when the density of the pest is too low to cause any substantial economic damage[18]. Using additional principles from ecology[19], we further argue that for low density pest populations sublethal insecticide concentrations are probably sufficient to precipitate their extinction. Stochastic dynamics and Allee effects (the effect of population density on mean individual fitness) can be sufficient to drive small populations of pests to extinction[19]. The original description of the Allee effect came from a pest management study. Allee[19] reported that tsetse fly baits did not need to catch 100% of the flies to drive a local population to extinction. Allee effects in low density populations can be due to reduced foraging efficiency, mate finding, reduced predator dilution or from inbreeding[20]. Sublethal effects of pesticides can exacerbate these effects if they damage the capacity of insects to find food, mates or to avoid predators[20].

Insects are probably exposed to mixtures of pesticides[3]. Insecticide residues that accumulate in the environment, and other pesticides such as fungicides, can have additive or synergistic effects, including on beneficial insects[3]. Interactions between pesticides influence how much need be applied to control a pest. Fungicidal treatments are well known for their negative effects on invertebrates[3,21]. For example, two of the most common fungicides affect the development of Colorado potato beetle larvae, and can increase the susceptibility of the pest to imidacloprid[22]. If interactions between pesticides are better understood, it may be possible to reduce the amounts of pesticide used even further by applying principles from community ecology to pesticide application[23].

What pesticide dose is needed to prevent economic damage to a crop?

Few pesticides dosage guidelines are given in terms of economic outcomes for the crop, or assurance of yield. Most studies of insecticide dosing solely focus on lethality to the target insect rather than the economic benefits of the treatments (and lethality is widely used as a marketing argument, see Table 1). In fact, demonstrating economic benefits from insecticide treatments is not straightforward[2]. In the United Kingdom, no clear gains in crop yields have been seen linked to increased neonicotinoid use[2], perhaps because neonicotinoids are often applied prophylactically where no pests are present or because their effects on beneficial insects may negatively affect yields[2]. If we are not seeing benefits from high doses of insecticides, we have an even greater imperative to rethink insecticide doses.

Applying insecticides at the minimum dose needed to reduce the target pests' fitness to zero will also help manage insecticide resistance. This echoes lessons learned from managing antibiotic resistance: manage resistance by tightly controlling and minimizing antibiotic use[24]. By contrast, widespread prophylactic use of long-lived pesticides at high doses is alarmingly common[2], which may explain why insecticide resistance keeps increasing globally[2,25].

Controlling pest resistance on the long term will only be achieved by an IPM approach[25]. This should involve multiple IPM strategies, such as crop rotation, the use of short-lived pesticides and alternating pesticide treatments with different modes of actions[25]. Reducing the dose of pesticide will additionally slow the development of resistance in populations by reducing the extent and intensity of the selection pressure for insecticide resistance.

Rethinking necessary insecticide doses

Arguing to end-users that total eradication of pests is not needed to assure their economic returns will require changing expectations. It will take some serious re-education to reassure growers that a low pesticide dose that may leave some pests visible in a crop has worked to protect the crop. There is also work to be done to assure growers that a lower dose will be sufficient to protect their livelihoods. But a benefit to farmers will be that a lower insecticide dose will be cheaper to apply and cause less damage to beneficial insects such as pollinators.

We do not pretend that this will solve the problem of declining insect populations. Reducing insecticide dosing will not eliminate insecticide residues, but it will reduce the severity and the scale of the problem. This could be done now with no cost to crop yields. It may be a short-term, temporary and partial patch across a far larger and more complex problem, but perhaps this patch can help us win time to change pesticide regulatory processes, shift to an IPM culture and globally redesign the model of food production into a more sustainable form. ❐

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Competing interests

The authors declare no competing interests.

Additional information

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