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Ecological selectivity of pesticides and pesticide application methods

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Abstract: There has been a lot of emphasis over the years on the development and use of pesticides that are specific and/or physiologically selective. This is a property of the chemistry and mode of action of the pesticide and the physiological and biochemical attributes of organisms. However, there is also the potential to make pesticides more selective through their judicious use, based on critical selection, timing, dosage, placement and formulation of pesticides (which are often broad spectrum). This paper discusses approaches to increase the ecological selectivity of pesticides and pesticide application methods, in the context of Integrated Pest Management in *Brassica* crops. Topics covered include minimisation of the dose applied, controlled release and dropleg technologies and the impacts of seed treatments on non-target species.

Key words: Pesticide, seed treatment, Integrated Pest Management, ecological selctivity

Introduction

According to David Pimentel, 20 years ago, less than 0.1% of the pesticides applied reached their target pests (Pimentel, 1995). This was partly due to 'poor' application methods and partly because of the minuscule amount of pesticide either picked up or consumed by the pest. At the time, Pimentel was describing the application of pesticides mainly by sprays, including aerial spraying, and both pesticide chemistry and application technology have improved since then. However, a considerable proportion of pesticides are still applied as sprays, either to crop foliage or to the soil, and this continues to be a relatively untargeted method of application.

Bartlett (1964) defined pesticide 'selectivity' as the capacity of a pesticide treatment to spare natural enemies while destroying the target pest. 'Selectivity' differs from 'specificity', which is the capacity of a compound to cause high mortality in a particular species (Fisher *et al.*, 1999). Physiological selectivity results from 'physiological differences in the susceptibilities of pest and natural enemies to a pesticide', whereas ecological selectivity results from 'differential exposure of pests and natural enemies to a pesticide' (Fisher *et al.*, 1999). In this paper we broaden these definitions beyond the effect of pesticides on natural enemies to include impacts on other non-target species in the natural environment.

There has been a lot of emphasis over the years on the development and use of pesticides that are specific and/or physiologically selective. This is a property of the pesticide's chemistry and mode of action and the physiological and biochemical attributes of organisms

(Fisher *et al.*, 1999) and, for example, pirimicarb is a relatively selective compound, being effective against sucking pests such as aphids but having considerably less impact on insects from other taxa.

There has also been consideration of ecological selectivity, which is the judicious use of pesticides, based on critical selection, timing, dosage, placement and formulation of pesticides (which are often broad spectrum). For example, there has been quite a lot of emphasis over the years on appropriate timing of pesticide applications, as evidenced by the considerable amounts of research on monitoring and forecasting systems for pests and pathogens and their subsequent uptake by farmers and growers.

Discussion

Minimisation of pesticide dose

When considering the total amount of pesticide applied per unit area there are a number of approaches that can be used to minimise and localise the dose applied. Application of the organophosphorous insecticide chlorpyrifos is a good example. This is a relatively broad spectrum pesticide and has been used successfully in the UK and elsewhere to control pest insects such as the cabbage root fly (*Delia radicum*). Table 1 shows examples of the amounts of chlorpyrifos applied per hectare using four methods of application to vegetable brassicas (some of which are no longer available in the UK). These methods have been ranked in terms of general efficacy for cabbage root fly control based on overall results from a range of insecticide trials (R. Collier & A. Jukes, personal communication). The most effective treatment is the module drench treatment and this uses an application rate/ha that is < 10% of the rate used for a field drench, which is often a less effective treatment. The seed treatment used approximately 2% of the active ingredient of the module drench treatment and in most cases was sufficiently effective. This treatment is no longer available to several European growers.

Table 1. Amounts of chlorpyrifos typically applied per hectare using a seed treatment, a pre-planting module drench and a field spray (e.g. for 30,000 plants/ha). N.B. the ranking of efficacy for control of cabbage root fly is based on experience from experimental work undertaken at University of Warwick over several years.

Treatment	**Rate applied**	**Amount of chlorpyrifos applied per hectare (g)**	**Ratio compared to seed treatment**	**Ranking of efficacy for control of cabbage root fly**
Seed	9.6 g a.i./ 100,000 seeds	2.9	1	2
Module drench	4.5 g a.i./ 1000 plants	135	47	1
Spray	0.9 kg/ha (2 applications allowed per crop)	900	310	4
Field drench	31.5 g a.i./ 1000 plants	945	325	3

A further consideration in respect of IPM is that both the seed treatment and the drench treatment must be applied prior to transplanting and so could be considered to be 'prophylactic' treatments. However, this 'disadvantage' may be outweighed by their greater efficacy, particularly when related to the dose of pesticide applied. Since the drench treatment is normally applied on the day before transplanting, it might be possible to omit it if the pest pressure was considered to be sufficiently low. Such decision-making might be assisted by the use of simulation models to predict pest phenology and abundance.

Seed coating treatments containing pesticides have been used widely for many years and have often controlled both pests and pathogens very effectively. More recently sowing time treatments with some pesticides have been applied using 'dummy pills'. A 'dummy pill' is a carrier for seed treatment solutions that may be phytotoxic and reduce seed germination; the pellet contains a dead seed of the same species to fulfil regulatory conditions. Nowadays 'seed treatment' is not the only way to apply small doses of pesticide and in recent years a 'phytodrip' treatment has been developed by Syngenta. This allows for the precise application of a very small amount of insecticide to a seed in a module at sowing time. At present, both dummy pills and phytodrip treatments can be used only with crops grown in cells for transplanting at a later date as similar techniques have not been developed for use on drilled crops such as oilseed rape.

Many compounds (whether applied as a drench, seed or phytodrip treatment) are relatively immobile and remain in the vicinity of the seed, controlling pathogens or pests within that zone. In more recent years, some more mobile compounds have been used in seed treatments (and could potentially be used in drench treatments) and this is particularly the case with neonicotinoid insecticides (imidacloprid and its successors) which have dramatically improved the control of certain pest insects, particularly sucking insects such as aphids, which are often inaccessible to contact-acting insecticides applied as foliar sprays because they are 'hidden' within foliage.

Impacts of seed treatments on non-target species

In principle, the possibility of applying very small amounts of pesticide, using seed treatments or similar approaches, and still obtaining effective control, has been a great advance and in most cases it would be accepted that if the seed is handled appropriately, so that it is buried and does not constitute a threat to birds and other wildlife, then less pesticide is 'wasted' and the risk of environmental contamination is reduced considerably. Not only is a smaller amount of pesticide applied, but it is also applied in a more targeted way which reduces the exposure of non-target organisms to pesticide residues, as is 'unavoidable' with pesticide sprays.

More recently the environmental credentials of certain seed treatments containing the relatively mobile neonicotinoid insecticides have been questioned due to concerns about the impact of insecticide residues that are translocated within flowering crops such as oilseed rape. This is particularly in relation to honeybees and other pollinators (Godfray *et al.*, 2014). Within the EU there is currently a 2-year ban on the use of these treatments on flowering crops to allow for the collection of more evidence to support or refute the concerns. It is outwith the scope of this paper to discuss this evidence in detail but it is important to highlight the other consequences, potential or otherwise, of the ban. Neonicotinoid insecticides control the pest beetles and aphids of oil seed rape very effectively and in the first autumn following the ban it is apparent that some pests are not being controlled effectively by the alternative treatments applied (e.g. *Psylliodes chrysocephala*; P. Kendall, personal communication). In some cases this may be attributable to pesticide resistance. Secondly, the alternative treatments to which farmers will revert may not themselves have good environmental credentials, although their adverse impact may affect different non-target species to bees and other pollinators. Thirdly, if adequate control is unachievable with the tools available to farmers then they may choose not to grow oilseed rape in the future, which will reduce the total number of flowers available to pollinators. All of these consequences should be considered in future environmental risk analyses when additional data have been obtained (Godfray *et al.*, 2014). One approach to decision-making may be to use an ecosystem approach, evaluating the ecosystem services delivered by farming, by pollinators, by other non-target species and the likely impact of different strategies of pest control on all of these.

Controlled-release technology

The principle advantage of controlled release formulations is that they allow less pesticide to be used for the same period of activity (Mogul *et al.*, 1996). Pesticides applied conventionally are subject to leaching, evaporation and degradation (photolytic, hydrolytic and microbial). Many of the pesticides that are readily biodegradable, and would be desirable, are highly toxic and because of their mobility in water and air their application is also a danger to non-target species (Mogul *et al.*, 1996). If they are chemically contained within a polymer or some other carrier they should become less toxic, since all the active ingredient will be released gradually over time. There may also be advantages in terms of reduction in phytoxicity. It seems that in terms of application of pesticides the technology has not been exploited as widely as it might be in terms of maintaining/increasing efficacy whilst reducing environmental impact. This might be related to the potential cost of such treatments.

Dropleg technology

If sprays are to be applied to control pests and pathogens then the dropleg technology for spraying the lower surfaces of foliage of vegetable and field crops, which was developed at the Federal Research Station Agroscope in Switzerland, may be a useful approach (Rueegg *et al.*, 2006). It was introduced to the market through collaboration between Amazone, Lechler, and Syngenta. Dropleg sprayers consist of plastic drag hoses with spray nozzles fixed on their tip. The application of pesticides to the lower surfaces of foliage has several advantages, such as reduced spray drift, as well as increased efficacy of non-systemic pesticides, especially against plant pests such as aphids or cabbage whitefly larvae which are ‘hidden’ amongst the foliage.

Impacts on pesticide resistance

The ‘principles’ of pesticide resistance apply to all methods of pesticide application in that the risk of resistance developing is strongly related to the selection pressure to which the pest or pathogen population is exposed. This is determined by how frequently members of the population encounter the pesticide, both in space and time, and by the proportion of the population that is exposed. The properties of the pesticide treatment, including the dose applied and its persistence in the plant/environment, are obviously key factors. The use of more targeted treatments such as seed treatments versus spray treatments will not necessarily reduce the risk of resistance developing *per se*. Indeed target organisms may be exposed to a lower selection pressure through the use of spray treatments, where the insecticide is dissipated and exposed to variable weather conditions and sunlight, than through the use of seed or drench treatments where pesticide breakdown may be slower.

Ecological selectivity and IPM

Integrated pest management ‘*means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection* *products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment*' (DIRECTIVE 2009/128/EC**)**. The aim of IPM strategies is to use all of the tools available to reduce farmers' reliance on a small number of treatments that might have an adverse impact on the environment (especially non-target and possibly beneficial species) and might also provide a high selection pressure for resistance. Thus any approach that reduces 'unnecessary exposure' of pests and other organisms to harmful treatments should be considered. At present, the range of 'non-pesticidal' methods of pest, disease and weed control is too limited to maintain 'food security' without the intervention of synthetic pesticides. Therefore, all approaches to increasing the ecological selectivity of pesticides should be considered, including different methods of pesticide formulation and application.

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