Sustainable Management of *Varroa destructor*

Keith S Delaplane, PhD

As varroa's resistance to fluvalinate spreads, we must turn to alternative control methods

NOT LONG ago I was conducting training workshops for beekeepers in Honduras. The routine was to travel from village to village and give day-long PowerPoint lectures covering everything from bee biology to genetics to breeding to pest control. I consider myself a moderately engaging lecturer, but on most days my audience would begin fading as the afternoon hours dragged on.

The scene always changed at the point when I announced I would now talk about drugs and miticides. Eyes popped open, backs straightened, notebooks emerged and my audience was transformed in an instant from so many vague forms melting in their seats to attentive cadets, pencils ready. 'Now for something important', you could read in their expressions.

BEEKEEPERS LIKE CHEMICALS

That experience taught me something. Beekeepers like to use remedial chemicals. I have seen that truth confirmed many times the world over. And I understand why. There is something proactive about inserting a miticide strip in your hives to knock back varroa. Something responsible. 'I'm not leaving anything to chance,' one says to himself, 'This is the right thing to do.' I know this warm feeling because I've experienced it myself when I slide a fluvalinate strip between the combs.

It's also easy to understand because, well, miticides work. They kill mites. And they kill them quickly with no obvious harm to the bees. So what's the problem?

A DEFENCE

So what is the problem with pesticides? This is not a trivial question and the answer is neither trivial, nicely-packaged, nor simple. But the fact is there are problems with acute toxins in bee hives. Our search for these problems has been a natural outcome of a sea change in society's way of thinking about land use and food production. This shift transcends the scope of this paper, but suffice it to say we live in a time of heightened awareness of the subtle – some would say insidious – effects of pesticides in the environment.

Although this position can be pushed to irrational ends, I think its basic premise is right: pesticides, although expedient and effective, have unavoidable, negative and unknowable consequences far down the cause-and-effect chain. It is best to think of pesticides as a last resort after a string of prior control measures.

Claire Waring

Beekeepers like using remedial chemicals which are quick and easy, so what is the problem?

LOSS OF VIGOUR

In much of the developed world there is a sense that the vigour and productivity of honey bees have declined in recent decades. I will not stir that pot other than to offer my prediction that if and when a research-based catalogue of causes emerges, it will include pesticides – and these will also be ones designed for use inside beehives.

There are data to support this. Certain formulations of formic acid increase adult bee mortality and interrupt brood rearing[1]. One study found a downward trend in lifespan and sperm loads of drones reared in the presence of fluvalinate[2]. Another study showed a reduction in body weight, ovary weight and stored sperm in queens reared in the presence of coumaphos[3]. Yet another study showed a 50% worker rejection rate of queen larvae reared in wax cups laced with 100 mg/kg of coumaphos and those queens that survived to adulthood had lower body weight than the control group[4].

What makes these latter results so striking is that 100 mg/kg is the legal tolerance level recognised by the US Environmental Protection Agency for coumaphos in beeswax.

NON-TARGET EFFECTS

It is worth stating that the non-target effects of pesticides on a host (bees in our case) are always neutral at best. The default setting is negative. In the absence of evidence, we can rationally presume that whatever biological system we choose to examine will be compromised if it is breached by a pesticide.

It is also worth stating that the non-target effects of pesticides are not only harmful at worst, neutral at best, or unknown – but the extent of their effects is unknowable. Cause-and-effect is not so much a chain as a web. The ultimate outcomes of inserting a pesticide, say flumethrin, into a system as complex as a honey bee colony are so numerous as to approach infinity – and therefore the reaches of scientific detection.

To offer a purely fictional example, let's say that flumethrin interacts with the terpenes in pine lumber used in beehives to impair the expression of genes responsible in worker bees for recognizing queen pheromone. Such a colony would be handicapped at many levels. More to the point, this fictional cause-and-effect chain is relatively simple because it involves only one primary cause, two intermediary causes and one effect, but even this simple chain poses a formidable challenge to scientific detection.

It would take years of experiments and serendipitous observations to discover the phenomenon, to say nothing of imaginative scientists to take an interest in the first place. The point is – such unpredictable secondary effects do exist and possibly explain many of the mysterious morbidities that afflict beekeeping.

WHY NOT WIN/WIN?

No one seriously disputes the notion that pesticides are inherently hazardous, so for much of the modern era, farmers and policy makers have used models that weigh the risks to the host and environment against the benefits realised by controlling a pest.

But such an approach presumes that we must take the bad with the good. Why should we settle for this? Why not invest rather in management practices that deliver pest control without jeopardising the health of the host or its environment? Why not invest in a pest management philosophy that rejects a risk/benefit approach in favour of a win/win approach?

This is the sort of thinking that animates a movement known broadly as sustainable agriculture. It's all in the name. Agricultural practices that are sustainable are ones that preserve land fertility, maintain plant and animal productivity, control pest and disease organisms and enrich rural economies for present as well as future generations. This is done in part by incorporating, not ignoring, concepts normally read about only in ecology books: nutrient cycles, predator/prey relationships, pollinators, habitat complexity and species richness.

The boundary between agriculture and ecology grows fuzzy because ecology is recognised as a player in the game. And because ecology is given economic value, there is an ethic of environmental stewardship permeating the movement.

ECONOMIC VIABILITY

This is all fine and good – if it works. It is unreasonable to ask farmers to practise environmental stewardship at the expense of profits. Fortunately, available evidence is promising. I cannot disclose pre-publication details, but my lab is preparing a paper that documents economic viability of a sustainable varroa management system.

In a more general example, it was shown in Alberta, Canada, that yields and profits in canola (oilseed rape) were maximised when 30% of the land within 750 metres of field edges was left uncultivated as sanctuary for wild pollinators[5]. This result contradicts conventional thinking that would have opted for maximum acres under cultivation and demonstrates the economic value of an ecosystems approach to food production.

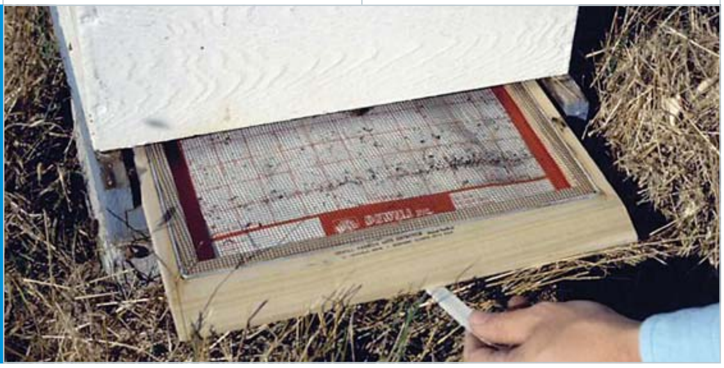
At this point we must leave a general discussion of sustainable agriculture to focus on that subset concerned with sustainable varroa mite management.

A PRIMER

Sustainable agriculture was preceded by a movement that started gaining voice in the 1960s. This was a time when the popular press was beginning to expose some of the excesses of chemo-centric pest control.

One of the driving motivations for change was a realisation that repeated applications of the same pesticide quickly select for pesticide resistance. It was recognised that resistance could be reduced or reversed if farmers expanded their pest control measures to include non-pesticide practices such as crop rotation, beneficial organisms and genetic host resistance.

It was further recognised that control was optimised when more than one measure was employed, preferably at different points in the pest's life cycle.



Photos by Keith S Delaplane

Fig 1. A bottom board sticky sheet is generally regarded as the most reliable estimator of colony varroa mite populations. A sticky sheet of paper is placed under a screen which protects bees from entanglement in the adhesive. The whole assembly is inserted onto the hive floor. After 3–7 days the screen is removed, mites counted and the average mite drop per day calculated

It is this integration of many control strategies, in favour of dependence on any one, that gives the approach its name – integrated pest management, or IPM. Today IPM is recognised as a central pillar of sustainable agriculture.

IPM

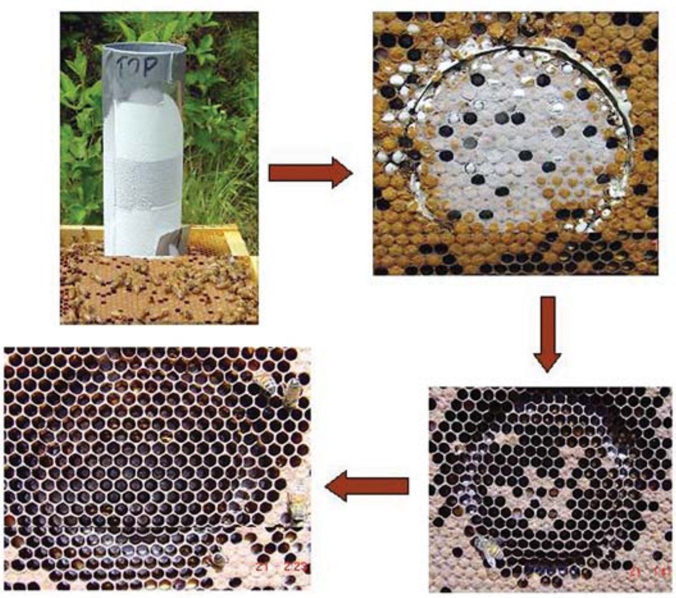
The first step in developing an IPM programme against a particular pest is to determine what density of the pest warrants control. This implies that certain pest levels are non-damaging and do not warrant a pesticide application. It also recognises that certain pest levels are damaging and if left uncontrolled will cut into the grower's profits. The trick is to determine that pest level in the middle – the level at which the farmer is justified in applying a pesticide in order to prevent a growing pest population from achieving the economic injury level.

That intermediate level is called variably the Economic threshold, Action threshold or Treatment threshold. Treatment thresholds are sometimes derived by grower experience or expert opinion, but the best ones are derived by controlled research – the more region-specific the better.

TREATMENT THRESHOLDS

We who keep bees in the UK or USA are fortunate to have some of the world's best developed treatment thresholds for varroa mite.

Fig 2. Hygienic behaviour is one of the most important heritable honey bee traits for mite and disease resistance. One way to select for it is to freeze-kill brood in the field with liquid nitrogen and measure the percentage removal rates by bees.
In this figure, a metal canister is screwed into a patch of sealed brood (top left), liquid nitrogen poured in to kill brood, the frame returned to the colony and the frame removed after 24 hours to calculate the percentage of freeze-killed brood cells removed by the bees. In the bottom right image, the bees are expressing a moderate degree of hygienic behaviour, while expression is 100% in the bottom left image



It is generally believed that the most reliable sampling method is that involving a screen device on the hive floor that traps and collects mites when they fall off bees (Fig 1). The beekeeper can remove the screen after 3–7 days, count the mites and derive a value for mite drop per day.

In my country we recognise a late season (August) treatment threshold for the Southeast as 60–190 mites per day[6] and for the Pacific Northwest, 23 mites per day[7]. Early season values are more congruent at 1–12 in the Southeast and 12 for the Pacific Northwest.

UK ON-LINE CALCULATOR

Beekeepers in the UK are fortunate to have an on-line calculator that derives a treatment recommendation based on the month sampled, length of brood rearing season in one's area, quantity of drone brood present and number of mites found in one of two sampling methods.

This is quite simply the most user-friendly yet sophisticated model of its kind and I recommend it highly for beekeepers in the British Isles. This resource is available at the National Bee Unit (NBU) website: http://beebase.csl.gov.uk/public/BeeDiseases/varroaCalculator.cfm

BELOW THE THRESHOLD

Once armed with a region-specific treatment threshold, a beekeeper's goal in sustainable varroa management becomes clear: to keep mite levels below the threshold as long as possible, preferably forever. This can be done by using a number of non-pesticide practices developed over the years, keeping in mind that one of the tenets of IPM is to attack a pest at as many different points in its life cycle as possible.

I will now talk about some of these IPM practices. The volume of published research on varroa IPM is large and the references that follow are by no means exhaustive.

GENETIC HOST RESISTANCE

One hallmark of IPM is genetic host resistance. In the case of varroa, it has been slow-going to derive lines of *Apis mellifera* that demonstrate measurable resistance to this non-natural parasite. But the potential advantages are enormous and well worth the pursuit.

For one thing, genetic host resistance is active around the clock and year-long. It requires no more labour than the beekeeper would realize in ordinary requeening schedules. And finally, the last ten years have seen the development of honey bee stocks that significantly limit varroa populations by way of specific heritable attributes.

GENETIC RESISTANCE

So-called hygienic bees are able to detect abnormalities in sealed brood, open the cells and remove the compromised contents (Fig 2).

This behaviour is useful against brood diseases as well as varroa[8] and has been shown to delay

Fig 3 (right). Varroa mites enter drone brood in preference to worker brood. Beekeepers can insert whole frames of drone cells into colonies during periods of drone rearing. Once these cells are filled and capped, the frame can be removed and frozen to kill a disproportionately large fraction of the colony's varroa mite population

Fig 4 (below). The majority of experimental evidence suggests that mesh floors, compared to solid, increase brood production and reduce varroa mite populations

significantly onset of treatment threshold[9]. Another heritable behaviour is self-grooming by which a bee removes a mite from her body and gives it a lethal bite[10,11].

A further success story is the search by the US Department of Agriculture in the 1990s for a varroa-resistant population of honey bees in far-east Russia. This search was aided by local scientists and beekeepers – and was ultimately successful[12]. Subsequent field trials in the US have confirmed lower varroa densities in colonies headed by Russian queens[13] and these now constitute a growing fraction of the queens used by American beekeepers.

DRONE BROOD TRAPPING

This technique relies on the fact that varroa mites preferentially reproduce in drone brood over worker brood (Fig 3).

It involves inserting a comb of drone cells into the brood nest during normal drone-rearing season. Bees will fill the cells with drone brood, mites will enter them in large numbers and once the cells are capped, the beekeeper can remove the comb and freeze it, killing a disproportionately large fraction of the resident mite population.

Of course, drones are killed too and critics of the method complain that it represents a large energetic cost to the colony. However, this cost can be offset partially by returning the freeze-killed brood to the colony where the bees will subsequently cannibalise it, regaining some of their nutrient investment.

This technique has been shown to significantly reduce colony mite density[14].

MESH FLOORS

In North America there has been a resurgence of interest in a technique originally documented in Europe – the use of mesh floors (Fig 4).

In another paper, my colleagues and I reviewed some of this literature and contributed additional evidence in support of the practice[9]. In general, bottom screens 'exert a modest restraint on mite population growth and a modest stimulus to brood production'.

Since their effects are innocuous or good, they are considered one of those IPM practices – like genetic host resistance – that represent zero additional labour inputs by the beekeeper. Or almost zero. It is generally recommended that beekeepers in cold climates close the screens over winter.

POWDERED SUGAR DUSTING

It has been shown that coating varroa-parasitised bees with powdered confectioner sugar elicits a rapid mite fall[15]. Aliano and Ellis[16] expanded on this knowledge by developing a method to dust an entire colony.

A screened box with solid floor is attached to the front of a hive and a commercial bee repellent (Bee Go™) applied to run bees into the box (Fig 5). The box with bees is then removed, closed and the bees dusted with 225 g powdered sugar and gently rolled to ensure an even distribution of sugar (Fig 6).

After 20–30 minutes, during which bees are grooming themselves, the box is gently bounced over white paper to dislodge and remove mites from the mix (Fig 7). Then the bees are returned to their colony by dumping them into an empty hive body placed over the brood nest (Fig 8). The authors report a mite removal rate of over 76% with this method.

SUNNY APIARY LOCATIONS

There is evidence that by simply placing an apiary in a sunny instead of a shaded location, a beekeeper can expect significantly reduced rates of varroa mite population growth[17].

INTEGRATION

It is important that an IPM practitioner understands what to expect from any of the components highlighted above. It is simply this: to delay or prevent onset of the treatment threshold.

An IPM arsenal is useful only in the context of a sampling scheme that reliably informs the beekeeper of the mite density in his/her hives. As long as IPM is keeping mites below the treatment threshold, there is no need to apply an acute toxin.

Now a criterion like this leaves room for many possibilities. It's possible that IPM could fail, exercising no impediment whatsoever on mite population growth. It's possible that IPM could succeed spectacularly, exercising enough restraint on mites that they never achieve treatment threshold. It's possible that IPM could succeed partially, delaying treatment threshold but not preventing the need for a rescue pesticide application at some point.

RAISING THE ODDS

But the important point here is that the IPM practitioner raises the odds for success with each

Fig 5. Nick Aliano and Marion Ellis at the University of Nebraska (USA) have developed a way to dust a colony's entire adult bee population with powdered sugar to induce varroa mite drop and removal. A screened cage is first attached to the colony entrance. A commercial bee repellent, used to remove bees from honey supers at harvest, is applied to run bees into the box

Fig 6. 225 grams of powdered sugar are applied to the bees. The box is gently rolled to ensure complete coverage of the sugar

additional IPM component he adds to the mix. This is the 'I' in IPM – the powerful principle that control is optimised when the pest is attacked at more than one point in its life cycle. This idea is even more attractive when one considers that some IPM components represent zero additional labour and work around-the-clock. This is true, for example, for an IPM beekeeper who uses sunny apiaries, resistant queens and mesh floors.

Experimental support for the principle comes from Rinderer and co-workers[17], who showed enhanced mite control with sunny apiaries and resistant queens, and work by my colleagues and myself[9] which showed enhanced mite control with resistant queens and mesh floors. It is my belief that as IPM gains adoption among beekeepers and as genetic varroa resistance becomes more prevalent in honey bees, that the onset of treatment thresholds will become increasingly rare.

GUARDEDLY OPTIMISTIC

I am guardedly optimistic about the future of IPM and sustainable beekeeping in general. Guarded, because the ease and efficacy of pesticides are powerful incentives for individual beekeepers to sacrifice long-term ideals for short-term gains. Optimistic, because IPM's principles make sense environmentally, economically and ethically – and socioeconomic forces will continue pushing beekeeping in that direction. ◆

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Fig 7 (above). After 20–30 minutes the box is gently bounced over white paper to dislodge and remove mites from the mix

Fig 8 (left). Bees are then returned to the colony by pouring them into an empty hive body placed over the brood nest