Honey Bees and Pesticides

Part II

Facts and Common Sense

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PERSPECTIVES from the past and the present economic impact of pesticide related honey bee losses were presented in Part I of this series. Here, we review research conducted to date as it relates to such topics as; 1) the susceptibility of bees to pesticides, 2) stress and environment as they may affect this susceptibility, and 3) toxic residues found in bee hives. Moreover, we will attempt to explain why, in some instances, national pesticide use restrictions have failed to protect bees. When factual information is unavailable, we have attempted to provide meaningful interpretation of research results by drawing on existing knowledge from other diciplines. Our purpose is to present, as clearly as possible, existing knowledge of the biological circumstances that contribute to varying levels of bee mortality from pesticides.

Honey Bees Are Insects Too!

Too often we forget that honey bees are simply insects. All of us are guilty of this from time to time. Somehow we find it more appealing to believe that honey bees are special. But whether we like it or not, the fact is there is nothing particularly unique or exceptional about honey bees — unless it is that many of us make a living from them. Moreover, it is of the utmost importance that we accept and understand the similarities between honey bees and other insect species if we are to develop meaningful solutions to the honey bee/pesticide problem complex.

Careful study of the literature reveals that many insects behave and function in the manner of honey bees. That is, they generate and conserve heat, raise young, communicate, swarm, forage and store provisions (some even garden) and pollinate or otherwise provide food for mankind. And they do so just as efficiently as do honey bees. Some might argue that honey bees are unique because as a single species they express all of the above behavioral and physiological traits. But, "special" combinations of traits such as these are present in other insects, in animals and in plants where they are equally compelling. So, we must ultimately conclude that physiologically, behaviorally and biochemically honey bees are just insects, remembering, of course, that insects themselves are quite remarkable.

Insecticides are made to kill insects. Hence, it should come as no surprise that honey bees and pest insects are all susceptible to these poisons. Even the grotesque gyrations of poisoned and dying honey bees mimic the actions of other insects similarly affected. To be sure, various insect species have been shown to be affected to a greater or lesser degree by each of these chemicals and this has been shown to be true for honey bees as well. The individual vigor and reproductive ability of certain insects is even enhanced by some insecticides.[12] We must also keep in mind that other pesticides such as herbicides may harm honey bees and that some insecticides

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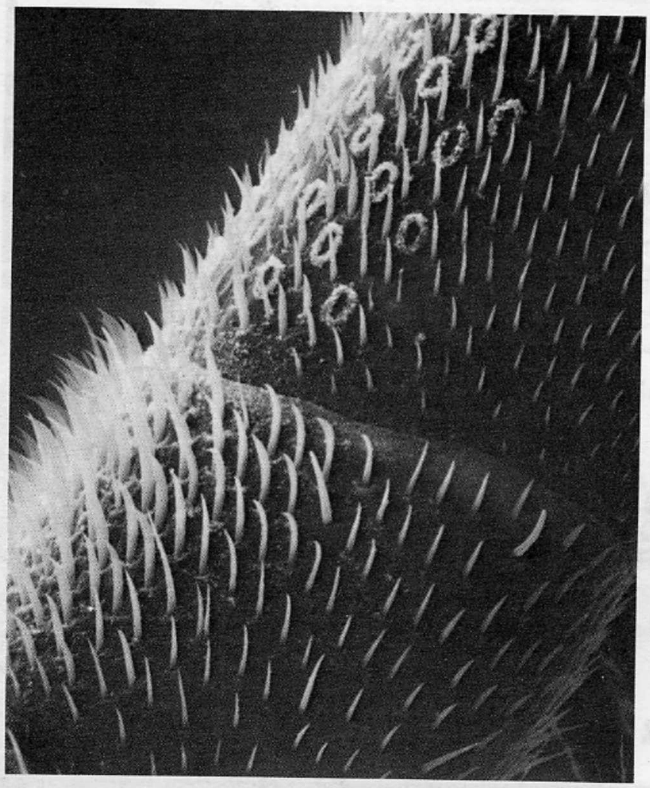

Accumulation of dust on the surface of a honey bee antenna. Beneath the thick circles of dust are the sensory receptors for odor. Particles of pesticide-laden foreign matter are likely to accumulate in similar fashion and foul the insect's abilities to detect aromas. Magnified 300 times.

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damage plants.[12] Finally, we must remember that many pesticides are highly toxic to various forms of life and persist in the environment for long periods of time.[10]

Understanding the origin of differences in susceptibility to the various pesticides/formulations is essential in the quest for chemicals that are less hazardous to bees. Susceptibility to an insecticide (or other pesticide) is governed by three factors.[29] First, there is the **relative toxicity** of the chemical which is mediated by the internal detoxification mechanisms that a particular insect species may have. Second, there is the **formulation** of the chemical which regulates both the incidence of contact and the quantity of poison likely to be acquired or ingested by the insect (honey bee in our case). The third is the **frequency of exposure.** The varying effects of environment and levels of bee foraging activity on these aspects of susceptibility must be considered in any analysis of the effects of pesticides on an organism: Environment may well be the most important aspect of bee/pesticide interactions.

Perhaps we will be fortunate and eventually find one or more agents that are effective against pest insects yet safe for bees. But, as a general rule, insecticides with low toxicity to bees can be expected to kill fewer

Honey bee gathering pollen from sweet corn.

targeted pest insects. Conversely, those highly toxic to pest species are also more toxic to bees. For now it seems that with a specific insecticide we are able to reliably reduce bee hazard only with differences in formulation, and methods of application (e.g. timing, rate, and application equipment).

Stress

The primary function of all living organisms, plants, animals and insects, is survival, and reproduction. There are certain environmental and biological extremes that circumscribe the optimal range of conditions wherein each species is able to live and develop normally, and outside of which struggles to survive and reproduce. In honey bees as in other life forms this range is quite narrow. The limits are genetically determined and undoubtedly vary among stocks and races of bees. Honey bees, for example, are able to control hive temperature and humidity when ambient (outside) conditions are within a certain optimal (yet undefined) range. However, when ambient conditions approach or exceed the limits of this range, a disproportionate share of the bees' energy must be devoted to survival (i.e. maintenance of temperature and humidity). If the business of survival takes all of the energy of an individual or colony, then no energy is left for other activities including reproduction and the production of surplus stores. The factors interfering with an organism's ability to function in an entirely normal fashion are collectively referred to as stress. Indeed, stress is undoubtedly a major contributor to reduced colony productivity. Unfortunately, stress in bees is both ill defined and difficult to measure.

Pesticides and their residues in the hive stress bees as do other factors such as weather extremes, food shortages, pests, predators, and disease.[8,43] Conversely, stress induced by other factors undoubtedly has a significant impact on the level of damage that a pesticide inflicts on a colony.

We must expect that the effects of each pesticide on a colony of bees may be different given different colony and environmental circumstances. For example, a strong colony in a moderate environment might be more likely to survive the effects of pesticide exposure than a weak colony in a more hostile environment. This effect could be mediated further by the chemical/formulation used. This reasoning could, for example, explain the value of hive waterers in reducing bee losses to pesticides in arid Arizona[32] where the colonies are probably moisture stressed.

Research has shown that waxes, including beeswax, have a high affinity for most organic pesticides.[34] Since organic molecules like insecticides and herbicides usually have a high affinity for lipids (waxes, fats and oils) they are absorbed, concentrated and bound up in beeswax,[10,34] (B. Erickson, unpub. data), the waxes and oils of plants[11,14,28] the oils and lipids of pollen grains,[26] and in the body waxes and fat bodies of animals including bees.[5,10,31] We digress momentarily to point out that this affinity of beeswax for naturally occurring fat soluble hive contaminants may have evolved as one of nature's ways of "cleaning the hive." If so, we must reexamine certain concepts of honey bee biology. For example, wax moths might be considered beneficial in the wild as they destroy naturally contaminated combs in dead or dying colonies, thus making suitable cavities habitable for new swarms.

In technical terms, many pesticides as well as many other organic molecules are hydrophobic (water hating) but lipophyllic (fat and wax loving). In honey and other water-based systems these compounds can migrate into lipids such as beeswax due to the partition coefficient (chemical affinity) that occurs between the two when they are in contact with one another.[36,10] But this natural cleaning mechanism that bees and beekeepers probably depend upon (along with certain detoxification mechanisms[42,58] to produce pure honey, may sometimes be disadvantageous. The system might become overloaded such that honey bees are stressed by continued exposure to pesticides, exposure to accumulating doses of a pesticide on plants or in the environment, or a combination of pesticides on plants, in pollen, wax combs and propolis. We need to determine the importance of stress related problems. This requires more knowledge of the thresholds for pesticide related as well as other sources of stress affecting bees.

Effect of Environment on Toxicity

Both the relative toxicity of insecticides and their persistence, either in the field or in the hive, are temperature and/or or humidity dependent (other environmental factors also play a role in degrading these poisons).[7,8,29] At low temperatures (i.e. below 50-60°F) most insecticides are not effective poisons (in part because the insects are not active) and label directions recommend against using them under these conditions. As a general rule toxicity rises as temperatures increase but residue persistence increases as temperatures decrease. Pyrethroid insecticides vary in at least one important way from this general rule as they **increase** in toxicity with decreasing temperatures. This may be why they appear "safe" for bees in some western (hot, arid) states while we found them highly toxic in over wintering colonies in Wisconsin (B. Erickson et al., unpub. data).

Bountiful cranberry harvest — the result of pollination by honey bees.

Conversely, with increasing temperature the persistence of insecticides in the field decreases; at very high temperatures residual activity is a matter of hours. This may well be why, in the 1940's and 50's in Arizona's heat, DDT was considered "safe" for bees while, at the same time, in cooler and perhaps more humid Utah its use caused extensive bee losses.[51] Some pesticides like ethyl and methyl parathion may volitilize in the hive and present an increased bee hazard.[5] In another example, we note that Lannate® is considered safe for bees in the western states where it dries rapidly on the plant but, in Wisconsin's more humid environment, leaf surfaces are rewetted by dew daily. Here,[9] and elsewhere when wet conditions prevail (C. A. Johansen, Pers. Communication) Lannate® has been found to be quite hazardous to bees.[9]

It is most important to remember that experience with bee mortality from each of the many insecticides (pesticides) available has been highly variable nationwide.[50] Environmental variance, as it affects 1) crop developmental rates and flowering, 2) bee foraging behavior, and 3) pesticide toxicity is a major reason why national pesticide use restrictions have not adequately protected bees.

A broader, more informed view of pesticides, their use and effects on bees, is needed. Since some differences in relative toxicity among pesticides may be environmentally induced and given the inherent variability known to exist among environments, plants, and pesticides, as well as bee activity, we need to capitalize on the existing diversity of pesticide formulations and perhaps seek new ones in order to minimize bee kills. Indeed, given a choice between one insecticide or formulation and another wherein more poison is carried back to the hive by foraging bees, we would opt for the former as the lesser of two evils. This would be especialy appropriate if less of the former is used because fewer pounds of active ingredient are applied per acre, fewer applications are required to achieve a satisfactory level of control, and/or environmental factors combine to reduce its hazard to bees. And, given that toxicity to bees is a question of both concentration and persistence, lesser field concentrations of chemicals with the same persistence are preferable. It is this line of reasoning that must ultimately be applied to all pesticides/formulations and all situations wherein pesticides are used near bees.

Almond orchard in full bloom. Thousands of colonies are rented annually for almond pollination.

Residue Accumulation and Persistence in Bees and Bee Products

In any given day bees from a colony or apiary will gather pollen and nectar from a variety of plant species. Hence, each of the pesticides used on any nectar and pollen source for bees can and will contaminate the hive, often simultaneously.[8] Perhaps the greatest weakness in our present system of diagnosing the causal agent(s) in every bee poisoning incident is the fact that residue analyses for all chemicals likely to have been applied in the area surrounding the affected bees are not made. The reasons for this are both simple and obvious. Residue analyses are expensive and time consuming. Typically, one particular pesticide known to have been applied nearby is suspected, analyzed for and found. And then invariably the analysts conclude that the suspected agent was responsible even though no further study is attempted. We can only assume that numerous bee losses have resulted from toxins other than that identified or from a combination of pesticides carried back to the hive.

Little is known about the persistence of pesticides in honey bee combs or the subsequent effects of these residues on honey bees. If pesticides are used on plants that honey bees forage and do not cause immediate acute bee mortality or economic losses of bees, they are usually considered "safe." Similarly, little is known of the relative hazard of various pesticide residues to bees in differing environments. For example, DDT was tested and considered "safe" for bees in Arizona. But in Utah, it was carried back to the hive, found in beeswax, pollen and propolis, and caused significant bee mortality.[19,24,51,53,54] Finally, insufficient attention has been paid to the long-term toxic effects of agricultural chemical residues on honey bees.

There are various ways by which bees may contact pesticides and carry them back to the hive. One ". . . is translocation of the poison to the nectaries and pollen of the treated plants. In this manner the chemical is made available to the bees to feed on and store in their hives."[2] Research on these systemic insecticides has found that foraging honey bees have brought back to the colony nectar from alfalfa, birdsfoot trefoil, field beans, citrus, fuchsia, *Nasturtium,* onion, and rape with residues of dimethoate (Cygon®);[17,27,30,39,56] from alfalfa, field beans, fuchsia, and *Nasturtium* with residues of phorate (Thimet®);[17,27] from rape with residues of phosphamidon and menazon;[39] from cotton with residues of demeton (Systox®)[35] from rape with residues of toxaphene (not known as a systemic insecticide);[22] and from mustard and borage with residues of Schradan,[2] one of the first synthetic organophosphate systemic insecticides four weeks after treatment. Alfalfa nectar contaminated with aldicarb (Temik®) and dimethoate reduced reproduction by and or killed alfalfa leafcutting bees.[18] Sysemic insecticides may not be hazardous to bees when used under certain conditions or when applied to some plants. Additional research pertaining to the occurrence of insecticides in floral nectar has been reviewed by Estep[10] and Mizuta and Johansen.[30]

Residues of several chlorinated hydrocarbon insecticides, their isomers or their breakdown products have been found in samples of wax cappings.[10] These include aldrin, BHC, DDT, heptachlor and lindane. Studies, conducted in Tennessee in 1973-76, found DDT and its breakdown products in a majority of samples even though the use of DDT in the United States was legally banned in January, 1971. These residues may have been the result of contact with contaminated bees, nectar, pollen, bee excretia or incorporated into the wax prior to secretion.

Moreover, this contamination may have resulted from the accumulation of these poisons over several seasons or from a single exposure.

Other research has shown that pollen contaminated by field applications of the following pesticides has been carried back to the colony and stored in wax combs: paris green, sulfur, calcium arsenate, DDT, malathion, polymer-encapsulated methyl parathion (Penncap-M®), methyl parathion from emulsifiable concentrate, ethyl parathion, methomyl (Lannate®), carbaryl (Sevin®), carbofuran (Furadan®), and permethrin (Ambush®) and (Pounce®). Arsenicals from paris green and calcium arsenate were present in pollen stored in comb and in bees analyzed six months after application.[52] Methomyl residues persisted in honey bee combs for eight months.[9] Methyl parathion (from Penncap-M®) persisted in various comb samples of stored pollen for 7 to 14 months after use,[9,21,37] (B. Erickson et al., unpubl. data), and carbaryl similarly persisted over winter for 7-9 months.[20,10] Small quantities of permethrin were found in some colonies 7 months after field exposure to treated sweet corn (*Zea mays* L.) (B. Erickson *et al.*, unpubl. data). Persistence beyond the time intervals given might have been shown had some of these studies been continued. Moreover, persistence would vary according to environment so the time intervals cited above must not in any way be considered absolute.

Field tests utilizing water sources contaminated with the herbicides paraquat and 2-4-5-T resulted in immediate acute colony mortality from the former and significantly reduced brood production from the latter. Residues of 2-4-5-T in bees (exposed to elevated dosages in sugar sirup) persisted for 1.3 years and in wax comb for 1.8 years.[34] Pentachlorophenol (used as a wood preservative on bee hives) persisted in bees, pollen and wax for more than two years.[23] Toxic residues of arsenical wood preservatives also persisted in bees and bee products for at least two years.[16] Clearly, the extensive use of certain wood preservatives may affect not only residue levels as they persist in the colony but colony performance and productivity as well.

The long-term persistence of many other pesticides and possible toxicants in colonies exposed under field conditions has not been determined. But, when wax combs were exposed to pest strips of dichlorovos[4,6,48] or colonies and caged bees were fumigated with resmethrin (H. Shimanuki, pers. comm.; E. Erickson and F. Moeller, pers. obs.), residues of these two insecticides persisted for at least 6 and 8 months respectively, in beeswax and "propolis." Colonies were unable to survive on combs that had been stored in a room fumigated with chlordane 9 months earlier.[44,55] Heptachlor used for ant control beneath colonies resulted in similar contamination (L. Atkins, pers. commun.). Malathion and methyl parathion from an emulsifiable concentrate were present in bee collected pollen following application but no residue persistence data were reported[1,46,49] (1979, B. Erickson et al., unpub. data). Endosulfan (a chlorinated hydrocarbon insecticide) residues were found in alfalfa pollen and nectar after bee mortality was experienced during field trials.[13]

Hence, the issue is not whether pesticides may or may not be carried back to the hive and persist there: **Most insecticides studied do get back to the hive and most persist as do other materials such as herbicides, wood preservatives and heavy metals.** The relative persistence of a chemical is undoubtedly dependent upon certain unique variables within individual colonies. Yet, because of this persistence, honey bees are now being used to bioassay for some environmental pollutants. Just as dairy cattle may feed on contaminated forage or lie on contaminating bedding and ultimatly concentrate chemical residues in their fatty tissues and milk,[57] so also may bees concentrate pesticides in their fatty tissues and in beeswax. As with cattle, this accumulation of toxins by bees may result from a variety of circumstances including air movement of pesticide contaminated dust and soil particles with subsequent uptake of these contaminants by plants.[57]

Given everything presently known in the fields of entomology and chemistry, we must presume that many pesticides are, because of their chemical affinities for lipids (including beeswax), similarly residual in bee hives. Hence, **we must be concerned with relative quantities** of each pesticide that are carried back to the hive. And as previously noted, given our present level of technology, this will ultimately be controlled by the active chemical itself; the product formulation including the presence or absence of adjuvants; and or the spray regime. For example, we now know that agents that stick the chemical to the plant (one class of adjuvants appropriately called stickers) may, under certain conditions, make transfer of the poison from plant surfaces to bees more difficult thus reducing the hazard to bees.[15,38] Also, timing (late afternoon or night application) may have a decided beneficial effect in some areas.

From the late 1940's to the early 1960's, the zenith of chlorinated hydrocarbon insecticide use, most bee/pesticide research was concerned with relative acute toxicity. When DDT was first banned, followed eventually by other chlorinated hydrocarbons because of their persistence (length of hazard) in the environment and in biological systems, there was renewed interest by many in the persistence of residues in bees and bee products (a few scientists like C. A. Johansen have stressed these concerns for decades). As a result the newer carbamate and organophosphate insecticides, now widely used, are accompanied by considerable data on residues in beehives. Unfortunately, we have less comprehensive such data on the chlorinated hydrocarbons, but we have to presume that these too persisted (and continue to persist like DDT in the fat cells of fish, birds, and mammals) in beeswax, pollen, and propolis (see 10).

Residues of insecticides and other pesticides in bees, pollen, and wax following field exposure have been detected most frequently at from 0 to 5 parts per million (ppm) when accompanied by bee mortality (more than 0.2 ppm may be lethal). These facts can be gleaned from study of the mass of available data (see for example[3,31,45,47]) Moreover, one research team found that parathion in bees is lethal above 0.3 to 0.03 ppm.[42] (Note: the lethal level should be expected to vary somewhat with circumstance.) Occasionally, unusually high levels (10-50 ppm) are detected. However, in most instances, these elevated levels can be explained by virtue of some peculiarity. For example, in the 1940's, extremely high levels of arsenic were noted when the insecticide drifted directly into the pollen traps used in the study or when colonies were situated down wind from copper smelters. Hence, when residue data indicate unusually high levels of insecticide (i.e. above about 5 ppm) these data should be considered exceptional and scrutinized for the occurrence of unusual circumstances. Higher initial residue levels beget increased persistence.

Although we can find little pertinent data in print, residue levels in dead and dying target insects also seem to fall within this 0-5 ppm range for most if not all insecticides.[25] We confirmed this in discussions with representatives of several chemical manufacturers who may gather but do not always release this type of information.

Pesticides harm (stress) honey bees in ways other than by causing mortality. Sublethal (less than 0.3 ppm) doses of parathion alter foraging activity by slowing flight speed and affecting the time sense of foraging bees. Communication of direction and distance information by dancing bees is also advrsely affected.[40,41,42] These effects would significantly reduce colony productivity. Carbaryl, dimethoate, and captan (a fungicide) induce morphogenic effects; that is, exposure to these chemicals results in the production of malformed adults (L. Atkins, pers. comm.). In laboratory studies it has been shown that several herbicides (again applied above field level dosages) either reduced bee egg hatch or brood production.[33] One must presume that many chemicals have other similar adverse effects which will be exposed by future research. Again we must emphasize that in most studies wherein bees were exposed to and died from pesticides, and the residues in bees and bee products determined, residue levels of 0.1 to 0.3 ppm in bees and bee products were extremely common. Much additional study of the long term sublethal effects of pesticides on bees is needed.

Our understanding of the interactions between bees, pesticides and the environment is still quite limited. Much additional research is needed. This lack of information is confounded by the many misconceptions about bees and pesticides. In Part III we will attempt to identify some of these misconceptions and talk frankly about the need to develop an integrated approach to crop management. This approach can permit bees, pesticides and crops to coexist in modern agricultural systems.

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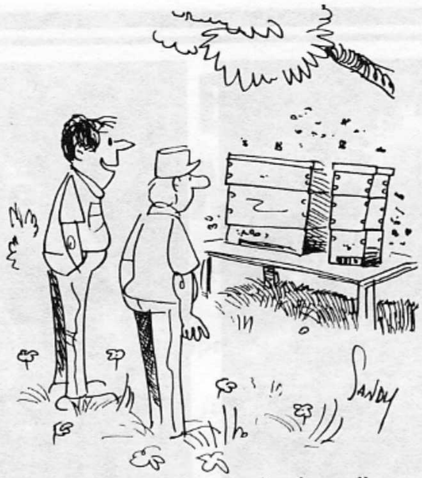

"And the other hive is diet honey."

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