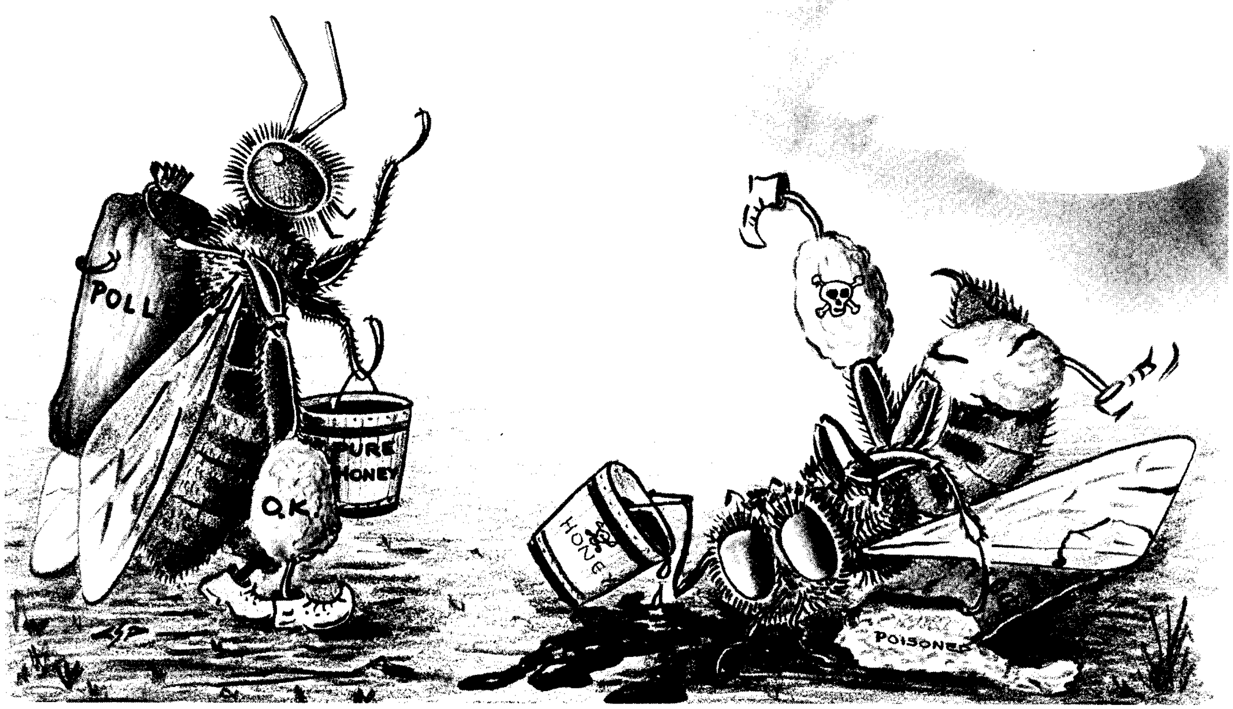
Reducing Pesticide Hazards to Honey Bees:

Mortality Prediction Techniques and Integrated Management Strategies



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Five hundred thousand bee colonies produced over $30 million in income for California beekeepers during 1979. In addition, every year honey bees are used to pollinate California crops worth over $800 million. For over 85 years this important industry has sustained serious losses from agricultural pesticide applications. With the introduction in recent years of new pesticides, the loss has been as high as 89,000 colonies in a single year. Chemical pest control in forests, recreational and residential areas, and on rangeland inflict even further damage to honey bees.

Practically every species of plant has diseases and insect, mite, or weed pests that can be treated with pesticides—acaricides for mites, fungicides for fungi, herbicides for weeds, insecticides for insects, and nematicides for nematodes. Perhaps it is no wonder that chemical poisoning overshadows all other bee problems, including bee diseases.

Still, most pesticides are not hazardous to bees. In a recent listing of the toxicity of 399 pesticides to honey bees determined from over 30,000 tests, 20 percent are highly toxic; 15 percent, moderately toxic; and 65 percent, relatively nontoxic or nontoxic to honey bees. Of the pesticides most commonly used on agricultural crops, less than 50 percent are highly or moderately hazardous to bees.

Pests must be controlled, but beneficial insects must survive. Over 50 of the 200 crops grown in the U.S.A. are pollinated by honey bees. They need our protection.

Comparative laboratory studies on the toxicity of pesticides to honey bees *(Apis mellifera L.)* were begun in 1950 and still continue at the University of California at Riverside. Field studies began in 1952. This publication reviews these studies, provides up-to-date information on pest management strategies, and tells how to predict and calculate pesticide hazards to bees.

U.C. RESEARCH SINCE 1950

Approximately 275 large commercial-size field tests have been made thus far. Over 65 different pesticides and pesticide combinations were evaluated for toxicity to honey bees. Effects were compared under different treatment conditions, such as day and night applications; airplane, helicopter, and ground machine application; high-volume, low-volume, and ultra-low-volume sprays; over or near covered and uncovered colonies; with dust and spray applications; with repellents, and with different pesticide formulations.

All toxicity tests were conducted in large commercial fields of crops in bloom and were highly attractive to honey bees. Most test crops were alfalfa, but some tests were made on ladino clover, cotton, milo, onions, and sweet corn, and in peach and citrus orchards. Some tests on peach and citrus trees, sweet corn, and alfalfa were made by power ground sprayers or dusters. All other tests on alfalfa, cotton and milo were airplane treatments. Other tests (not reported here) have been made to study hazards to bees in mosquito abatement control operations. Several parameters were used to measure the effects of these applications on honey bees.

Colony strength. All test colonies were inspected before and after pesticide applications. Colony strength was measured by determining number of square inches of uncapped and capped brood, number of frames covered with bees, condition of the queen, workers, drones, eggs, larvae, pollen, honey, and the like.

Dead bees at the colony. The Todd dead bee hive entrance trap was utilized to collect and retain bees dying at the hive.

Bee visitation in the field. Ten or more bee visitation counts (a count constitutes the number of bees foraging in 200 square feet of crop per minute) were made daily—usually at 10 A.M., 1:30 P.M., and 5 P.M. for several days before pesticide application and until the close of the test. In addition to field visitation records, counts were made at 1-minute intervals several times per day of bees leaving and entering the hive; activities of the pollen carriers and water carriers were recorded separately. In some tests, the cage method of Gary was used to make counts of bees leaving or returning to the colonies.

Caged bees in the field. Honey bee workers confined in a 5 by 5 by 5-inch (12.7 by 12.7 by 12.7-cm) 0.125-inch-mesh wire hardware cloth (3.175 mm) cages were placed in the field at the time of application to measure the initial contact poison effect. After application, other cages of bees were placed in the field at various intervals to study residual fumigation effects.

Foliage residue bioassay. Following pesticide application, residue was bioassayed by systematically collecting foliage from 10 areas within each plot, chopping it into I - inch (2.5 cm) lengths, thoroughly blending, and placing in pint (475 ml) cardboard cans. The lids of the cans were replaced with nylon tulle netting. Twenty-five worker bees were aspirated through a hole in the other end: the hole was then closed with a rubber stopper fitted with a glass vial containing honey-water food for the bees. Mortality of the bees in the cages was determined after 24 hours. A series of bioassays of the foliage residue was made periodically after treatment, until the absence of bee kill from continuous contact with contaminated foliage indicated that the pesticide residue was no longer toxic to bees.

Weather conditions. Temperature and humidity data were recorded continuously day and night for all experiments. Wind and cloud conditions and rainfall were recorded as necessary.

Bee behavior. Flight and other behavioral activities of the bees were recorded in treated and untreated plots.

Recent studies

Some pesticides are carried into the hive in contaminated pollen, where it is utilized to feed developing brood. Tests showed that some of the brood were killed and that some emerging adult bees were deformed. Captan and microencapsulated methyl parathion are two of the most serious examples of materials that cause this kind of damage.

Repellents are being developed to reduce pesticide kills of bees. Pesticide and repellent field studies have indicated the feasibility of reducing hazard to bees by adding a repellent to a toxic pesticide spray in field crop applications. In most of these tests, the repellent reduced bee kill from the toxic pesticide approximately 50 percent.

Night applications (from darkness until 4 A.M.) reduces bee kill approximately 50 percent and reduces overall bee hazard at least one category. For example, if a pesticide at a given dosage and applied early morning gives a bee hazard designated as "high," then the same pesticide at the same dosage but applied during the night will reduce the bee hazard to "moderate." The additional time provided by the night application before bees initiate foraging allows the pesticide residue to dissipate to a lower level of bee toxicity. On the other hand, applications of toxic pesticides after 7 A.M. are usually twice as hazardous as early morning applications.

Table 1

Effects of more than 600 pesticides have been measured on honey bees since these studies began in 1950. Relative toxicity to bees of 261 of these chemicals and many of their characteristics are given in Table 1. These ratings are based on field tests in agricultural crops, mosquito abatement districts and commercial applications with the more commonly used pesticides and laboratory data for the newer and the less frequently used pesticides.[1]. Except for the arsenicals (which act as stomach poisons), all of the chemicals in the highly toxic group (Group 1) show LD_{50} toxicity values (the amount of a pesticide that will kill 50 percent of the bees contacted) of less than 2 micrograms (,19) of toxicant per bee. The LD_{50} values are from 2 to 11 µg per bee for the moderately toxic pesticides (Group II) and above 11 µg per bee for the relatively nontoxic pesticides (Group 111). For the actual LD_{50} values of the more toxic pesticides, see Table 2.

A list of pesticides which are essentially nontoxic to bees at dosages above 11 µg per honey bee is given for 176 pesticides in Table 1, Group III. The registered trade names or common-name designation of other commonly used pesticides appear together in Tables 1 and 2.

Note that most of the defoliants, herbicides, and fungicides, and more than 60 percent of the acaricides and insecticides, occur in the relatively nontoxic Group III.

Table 2

Table 2 lists and groups 75 commonly applied pesticides according to their high or moderate toxicity, provides field data, and the laboratory data needed to predict pesticide hazard to honey bees. The LD_{50}, in micrograms per bee, the probit value (statistical unit of measure) used to express changes made by one variable (such as pesticide dosage) on another variable (such as honey bee mortality)[2]. Pesticide hazard to bees and residual toxicity information is based on field tests using dosages normally used in dilute water sprays on agricultural crops for controlling pest insects and mites. This latter information is usually not applicable for ultra-low volume (ULV), no-water sprays. It is applicable, however, for predicting hazard to bees from non-ULV mosquito abatement, forest, range, recreational, and yard treatments.

PREDICTING PESTICIDAL HAZARD TO HONEY BEES

Tables 1 and 2 can be used to predict the degree of toxicity hazard to honey bees in the field, when the pesticide is applied as an early morning spray. In most instances, the LD_{50} in micrograms per bee can be directly converted to the equivalent number of pounds of chemical per acre when applied as a spray to the aerial portions of plants. (For kilograms per hectare (kg/ha), multiply µg/bee by 1.12). For example, since the LD_{50} of parathion is 0.175 µg/bee, we would expect that 0.17 lb/acre of parathion would kill 50 percent of the bees foraging in the treated field at the time of application or shortly afterwards.

Generally speaking, a pesticide with a slope value of 4 probits or higher can often be made safer to honey bees by lowering the dosage only slightly. Conversely, by increasing the dosage only slightly the pesticide may become highly hazardous to bees. This information is particularly useful when the LD_{50} in micrograms per bee is approximately equal to the normal dosage in pounds per acre needed in the field to control pest populations. For example, consider a pesticide, which is normally applied at dosages of 0.5 to 1.5 lb/acre, having a LD_{50} of 1.0 µg/bee. Furthermore, suppose that the

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[1] Results of earlier research on this project have been published by Anderson and Atkins (1966; 1968); Anderson *et al*. (1968); Atkins, Anderson and Todd (1970); Atkins (1972); Atkins (1975); Atkins *et al*. (1975*a,b*); Atkins and Anderson (1976); Womeldorf, Atkins and Gillies (1974).

[2] **Slope** value is the trigonometric tangent of the angle made by a straight line with the x-axis of a graph—the deviation of a dependent variabley (vertical axis) with respect to the independent variable x (horizontal axis); the slope value is expressed in **probits**. a statistical unit of measurement of probability based on deviations from the mean of a normal frequency distribution; **dosage-mortality curve** !S the statistical expression of a linear-regression. represented by a straight line on a graph. used in a relationship between two variables so that a change in one (dosage of a pesticide) is accompanied by a proportional change in the other (mortality of honey bees).

pesticide has a slope value of 4.0 probits. Then, if this chemical is applied at 0.5 lb/acre, we would expect a 12 percent kill of bees; at 1 lb/acre, we would expect a 50 percent kill; and, at 1.5 lb/acre, we would expect a 72 percent kill.

Table 3

Table 3 shows additional examples of anticipated bee mortalities at other selected slope values with increasing and decreasing dosages of a pesticide having a LD_{50} value of 1.0 µg/bee. Any pesticide having a known LD_{50} value can be similarly read by substituting the LD_{50} (the 1.0 or center column) of Table 3 and multiplying the LD_{50} value by the other factors (0.1, 0.25, 0.5, 0.75, 1.25,1.5, 3.0, and 1 0.0) to obtain the proper range of dosages in pounds per acre. By using the value closest to the known slope value for the particular pesticide, the percent mortalities for that chemical can be predicted.

We wish to emphasize that the method described is a rule-of-thumb, and that some pesticides are more or less hazardous than one can anticipate from the laboratory data. Most of these are pesticides which have very short or very long residual characteristics.

The Honey Bee Mortality Predictor—a rapid method

The monogram (pp. 20-21) provides a quicker method of predicting the mortality of honey bees from field applications of pesticides than the one just discussed (Table 3), which requires mathematical calculations. The method is also useful for predicting potential hazards to honey bees when applying pesticides for mosquito abatement and for pest control in forest, rangeland, and recreational areas and home gardens.

An example of how the Predictor works: Let us say that parathion has a LD_{50} of 0.175 µg/bee; slope value of 4.96 probits. We intend to apply parathion at the rate of 0.25 lb/acre a.i. (active ingredient) to control pest populations of insects in an area which contains colonies of honey bees for pollinating the crop. How hazardous will this dosage be to the bee colonies if they cannot be protected during application or removed to safety?

Read the instructions given in the Predictor (pp. 20-2 1). Note that a LD_{50} of 0.175 µg/bee is equivalent to 0.175 lb/acre a.i. and that 0.175 appears in the LD_{50} or "x 1" column in the dosage table. You want to apply 0.25 lb per acre; in the dosage table this dosage appears under the "1.5 times the LD_{50}" column. The 1.5 indicates that 0.25 lb/acre is 1.5 x the LD_{50} rate of 0.175 lb/acre. Place a straightedge even with the " 1.5 dosage increase" level of the left vertical scale. Since the slope value is 4.97 probits (approximately 5 probits) rotate the straightedge through the 5-probit point (approximately one-third of the distance left of 4 probits between the 4 and 8 probit marks) of the "slope value" guide line. The straightedge now will intersect the right vertical scale, which is the "predicted percent mortality of honey bees in the field." You will note that the straightedge intersects the mortality scale at 78 percent. Therefore, the application of 0.25 lb/acre of parathion is predicted to kill approximately 78 percent of the bees that contact the treated foliage or that are flying through the treated area during the application of the spray.

Remember that bee mortality would be reduced approximately 50 percent (to 39 percent in the example) if the parathion application was made during the night (from darkness to 4 A.M.), and that bee mortality would be increased approximately two times if the parathion application was made after 7 A.M. and later into the day (more than 98 percent in the example).

INTEGRATED BEE MANAGEMENT STRATEGIES

Many pesticides are toxic to honey bees and other beneficial insects. The farmer, beekeeper, and pest control industry should cooperate closely to minimize losses of these insects and mites, using only the safest of the recommended pesticides (Tables 1 and 2). However, even though a pesticide may be highly toxic to bees, it may be effective against pests at a dosage low enough to cause minimal hazards. Examples are most pesticides used for mosquito abatement and many of the new pyrethroids. On the other hand, many toxic pesticides are nonhazardous, because they are applied only as seed treatments or as granular applications; and foraging bees do not directly contact them.

Understanding and utilizing bee behavior

Bees usually leave their hives to forage during daylight when temperatures are between 55 to 60°F (13-1 6°C). Clustered bees will usually enter the hive when the temperature lowers to 70°F (21.1°C). However, a strong wind may cause clustered bees to enter the hive at temperatures above 70°F. Bees in crowded hives are more likely to cluster than those in uncrowded hives. The time and intensity of bee visitation in a given crop depends on abundance and attractiveness of the bloom. For example, alfalfa and cotton crops in bloom may be attractive all day, while cucumbers are attractive near mid-morning and early afternoon and milo, corn and sweet corn are attractive only in the morning.

Location of bees

Colonies located within the field and "treated-over" may sustain higher losses than do colonies at the edge or outside the field that are not treated-over. Usually, injury is not significant to colonies a quarter of a mile or more away from applications, unless the treated crop is the only attractive field in the area. In this case, injury may occur to colonies several miles away. The farther the colonies are from the treated area, the less critical is the application time. Colonies moved into the field 2 or more days after treatment usually escape pesticide damage.

Time of application and location of colonies

Time of application and location of colonies may be important in relation to bloom period and attractiveness of the forage crop to honey bees. Treating when bees are foraging in the field is usually the most hazardous, and treating over colonies in hot weather when bees are clustering on the outside of the hives may cause severe losses. Treatments during the night and early morning before bees are foraging are safest. Treating a nonblooming crop with a hazardous pesticide, when cover crops, weeds, or wildflowers are in bloom in the field or close by may cause heavy bee kills. Pesticide drift to neighboring fields that are attracting bees may cause losses.

Pesticide formulations and application techniques

Treating large areas or repeating applications may cause greater bee kills. With few exceptions, pesticides applied as dusts are more hazardous to honey bees than those applied as sprays.

Pesticide spray formulations vary significantly in their toxicity to bees. Wettable powder formulations are often more hazardous to bees than are either emulsifiable or water-soluble concentrate formulations.

Fine sprays are less toxic than coarse sprays. Sprays of undiluted technical pesticide (ULV) may be more toxic than diluted sprays. Aerial applications of pesticides over bees in flight are more hazardous than ground applications. Granular applications are usually the safest method of treatment. Baits containing pesticide on materials such as apple pomace may attract bees resulting in death.

More than one pesticide is often applied in one treatment in California to control the entire pest complex present. Combinations of pesticides are less hazardous to bees than are the same pesticides used separately (as shown over the past 6 years of over 35 combinations of two to four pesticides used simultaneously). Using specific pesticides for each pest often enables the grower to select chemicals which are less hazardous than when using a high dosage of a broad-spectrum pesticide. Combinations of pesticide reduce the application costs and the number of treatments. Pesticidal contact with bees is reduced and thus bee mortality is reduced.

Covering colonies

Tarpaulins of burlap or dark plastic used to cover colonies tent-fashion for 1 or Z hours during and after application in early morning may give added protection from pesticides. Colonies may be covered for 2 or more days if the burlap tarpaulin is kept damp with water. Feed bags of burlap, thoroughly soaked in barrels of water for several hours, draped over only the hive entrances have provided satisfactory protection from pesticides for bee colonies near or in treated fields. This method does not prevent bee flight activity but disorients the foragers to the extent that foraging visits are drastically reduced.

Covering may be important when pesticides are applied by aircraft. In some instances, colonies should be moved away from the area entirely when highly toxic pesticides with long residual properties are to be applied.

Caution

Take care to use the proper dosage of the safest pesticide near bees that will give good pest control. Read the label and follow approved local, state, and federal recommendations. When using pesticides hazardous to bees, notify the beekeeper so that measures can be taken to protect colonies, or so that prompt, intensive care can be administered following poisoning to alleviate further damage.

It is the obligation of the beekeeper to post his name, address, and telephone number on his colonies and to register the locations of his colonies with local authorities. Thus, the pesticide applicator is made aware that colonies are present and that the names and telephone numbers of beekeepers are available for notification.

CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE REGULATIONS

Beekeepers, growers, pest control advisors, and pesticide applicators should know, understand, and follow the California Department of Food and Agriculture Administrative Code and Agricultural Regulations and the California Pest Control Operator Regulations for the Protection of Bees, such as Article 5, Section 3096. Current regulations may be obtained from the County Agricultural Commissioner.

TABLE 1—RELATIVE TOXICITY OF PESTICIDES TO HONEY BEES DETERMINED BY LABORATORY AND FIELD TESTS (CALIFORNIA. 1950 through 1980.)

(Number-keyed notes on their uses can be found below table)

GROUP I—highly toxic: Severe losses may be expected if used when bees are present at treatment time or within a day thereafter, except where noted to the contrary.

Pesticide (trade name and/or common name)

aldrin[2]

Ambush®[2, 18], permethrin

arsenicals[1, 2]

Avermectin®[17]

Azodrin®[1, 2], monocrotophos

Baygon®[2] propoxur

Baytex ®[2], fenthion

Bidrin ®[1, 2], dicrotophos

Bux®, bufencarb

carbosulfan[2] FMC-35001

Cygon®[2] dimethoate

Cythion®[2, 4], malathion

Dasanit®[5], fensulfothion

DDVP®[2], dichlorvos

Dibrom®[2, 3], naled

Decis®[2], decamethrin

De-Fend®[2], dimethoate

diazinon[2], Spectracide®

dieldrin[1, 2]

Dimecron®[2], phosphamidon

Dursban®[2], chlorpyrifos

Ekamet® etrimfos

EPN[1, 2]

Ethyl Guthion® azinphos-ethyl

resmethrin, Synthrin®

Sevin®[2], carbaryl

Famophos®, famphur

Ficam®, bendiocarb

Folithion®, fenitrothion

Furadan®[2, 5], carbofuran

Gardona®[2, 5], stirofos

Guthion®[1, 2], azinphos-methyl

heptachlor[1, 2]

Imidan®[2], phosmet

Lannate®[2], methomyl

Lorsban®, chlorpyrifos

malathion[2, 4]

Matacil®, aminocarb

Mesurol®, methiocarb

methyl parathion[1, 2, 11, 12]

Monitor®[2], methamidophos

Nemacur®[5], fenamiphos

Nudrin®[2], methomyl

Orthene®[2], acephate

parathion[1, 2]

Pay-Off®

Phosdrin®[1, 2, 3], mevinphos

phosphamidon[2], Dimecron®

Pounce®[2, 18], permethrin

Pydrin®[2], fenvalerate

Supracide®[2], methidathion

Tamaron®[2], methamidophos

Spectracide®[2], diazinon

Sumithion®, fenitrothio

Sumithrin®, *d*-phenoth

Temik®[1, 2, 5, 7], aldicarb

teppl[1, 2, 3] n

Vapona®[2], dichlorvosrin

GROUP II—moderately toxic: Can be used around bees if dosage, timing, and method of application are correct, but should not be applied directly on bees in the field or at the colonies

Insecticide (trade name and/or common name)

Abate®[2], temephos

Agritox®, trichloronate

Bolstar®, sulprophos

Carzol®[2], formetanate hydrochloride

chlordane[2]

Ciodrin® crotoxyphos

Counter®, terbufos

Croneton®, ethiofencarb

Curacron®, profenofos

DDT®[1, 2, 10]

Di-Syston®[1, 2, 6, 18], disulfoton

Dyfonate®, fonofos

endrin[1, 2]

Korlan®, ronnel

Larvin®[2], thiodicarb

Metasystox-R®[2], oxydemeton-methyl

Mocap®, ethoprop

Perthane®, ethylan

Pyramat®

Sevin®4-Oil[2], carbaryl

Sevimol®[2], carbaryl

Systox®[1, 2, 18], demeton

Thimet®[1, 2, 6], phorate

Thiodan®[2], endosulfan

Trithion®[2], carbophenothion

Vydate®[2], oxamyl

Zolone®, phosalone

GROUP III—relatively nontoxic: Can be used around bees with minimum injury.

Insecticides and Acaracides (trade name and/or common name)

Acaraben®, chlorobenzilate

allethrin, Pynamin®

Altosid®[17], methoprene

Birlane®, chlorfenvinphos

Comite®, propargite

cryolite[2], Kryocide®

Delnav®, dioxathion

Dessin®, dinobuton

Dimilin®[17], diflubenzuron

Dylox®[2], trichlorfon

Baam®, amitraz

Bacillus thuringiensis[17], Bactur®, Bactospeine®, Bakthane®, Dipel®, Thuricide®

nicotine[2]

Omite®, propargite

Pentac®, dienochlor

Pirimor®[2], pirimicarb

Plictran®[2], cyhexatin

pyrethrum (natural)

rotenone[2]

ethion

Fundal®, chlordimeform

Galecron®, chlordimeform

Heliothis polyhedrosis virus

Kelthane®[1], dicofol

Mavrik®[2], fluvalinate

methoxychlor[2], Marlate®

Mitac®, amitraz

Morestan®, oxythioquinox

Morocide®, binapacryl

Murvesco®, fenson

sabadilla[2]

Sayfos®, menazon

Sevin® SL[2], carbaryl

Sevin® XLR[2], carbaryl

Smite®, sodium azide

Tedion®, tetradifon

Tetram®

Tokuthion®, prothiophos

Torak®, dialifor

toxaphene®[1, 2]

Zardex®, cycloprate

Fungicides (trade and/or common name)

Afugan®[2], pyrazophos

Arasan®, thiram

Bayleton®, triadimefon

Benlate®, benomyl

Bordeaux mixture[2]

Bravo®, chlorothalonil

captan[11]

copper oxychloride sulfate

Dithane® D-14, nabam

Dithane® M-22, maneb

Dithane® M-45, manzeb

Dithane® Z-78, zineb

Du-Ter®, fentin hydroxide

Dyrene®, anilazine

ferbam

glyodin

Hinosan®, edifenphos

Indar®, butrizol

Karathane®, dinocap

Lesan®, fenaminosulf

Morestan®, oxythioquinox

copper 8-quinolinolate

copper sulfate

Cuprex®, dodine

cupric oxide

cupric hydroxide, Kocide®

Delan®, dithianon

Dessin®, dinobuton

Difolatan®, captafol

Morocide®, binapacryl

Mylone®, dazomet

Phaltan®, folpet

Plantvax®, oxycarboxin

Polyram®, metiram

Ridomil®

Sisthane®, fenapanil

Smite®, sodium azide

sulfur[2]

thiram, Thylate®

thyfural

Vitavax®, carboxin

ziram, Zerlate®

Herbicides, Defoliants, and Desiccants (trade andlor common name)

AAtrexi®, atrazine

alachlor

Alanap®, naptalam

Alopex®, clofop-isobutyl

Amex® 820, butralin

Amiben®, chloramben

amitrole

Ammate®, AMS

Aquathol K®, endothall, dipotassium

Avenge®, difenzoquat

Balan®, benefin

Banvel®, dicamba

Basagran®, bentazon

Basalin®, fluchloralin

DEF®[8]

Desiccant L-10®[1, 9],arsenic acid

Devrinol®, napromamide

dichlorprop[1], 2,4-DP

dinoseb[9], dinitrobutylphenol

diquat[8, 9]

Dual®, metolachlor

endothall, sodium salt, Accelerate®

Eptam®, EPTC

Eradican®, EPTC + safener

Evik®, ametryn

Evital®, norflurazon

Folex®[1, 8], merphos

Garlon®, triclopyr

Goal®, oxyfluorfen

Hoelon®, diclofop-methyl

Hydrothol 191®, endothall monopotassium salt

Betanal®, phenmedipham

Betanex®, desmedipham

Bladex®, cyanazine

Blazer®, acifluorfen

butachlor

butam

cacodylic acid[1]

Cambilenei®[1, 2, 3, 6]-TBA

Caparol®, prometryn

Casoron®, dichlobenil

Chloro IPC®, chlorpropham

Cotoran®, fluometuron

2,4-D[1,2]

Milogard®, propazine

Modown®, bifenox

MSMA[1]

Mylone®, dazomet

Nortron®, ethofumesate

Paarlan®, isopropalin

paraquat[1, 9]

Planavin®, nitralin

Pramitol®, prometon

Preforan®, fluorodifen

Princep®, simazine

Probe®, methazole

Prowl®, pendimethalin

Ramrod®, propachlor

Randox®, CDAA

Ronstar®, oxydiazon

Roundup®, glyphosate

Hyvar®, bromacil	Sancap®, dipropetryn
Igran®, terbutryn	Sencor®, metribuzin
IPC®, propham	silvex[1], 2,4,5-TP
Karmex®, diuron	Sinbar®, terbacil
Kerb®, pronamide	Smite®, sodium azide
Lasso®, alachlor	Surflan®, oryzalin
Lorox®, linuron	Sutan® +, butylate
Maloran®, chlorbromuron	2,4,5-T[1, 2]
MCPA[1]	Telvar®, monuron
Methar®[1], DSMA	Tenoran®, chloroxuron
	TOK®, nitrofen
Tolban®, profluralin	Turf Herbicide®, endothall, disodium
Tordon®, picloram	Vegadex®, CDEC
Treflan®, trifluralin	Zorial®, norflurazon
endothall[13]	N-Serve®[15], nitrapyrin
Exhalt® 800[14]	Polaris®[16], glyphosine
gibberellic acid[13]	Smite®[5], sodium azide
Mocap®[5], ethoprop	Sustar®[13, 16]
Mylone®[5], dazomet	

Number-keyed Notes on Pesticide Uses

1. California state regulations require permits for most uses of these chemicals, also for 2,4-D and Z,4,5-T as herbicides but not as sprays on citrus.
2. Laboratory- and field-tested mainly on alfalfa, citrus, cotton, ladino clover, milo and sweet corn; all other chemicals were laboratory-tested only.
3. Dibrom®, Phosdrin®, and tepp have such short residual activity that they kill only bees contacted at treatment time or shortly thereafter. Usually safe to use when bees are not in flight; not safe to use around colonies.
4. Malathion has been applied on thousands of acres of alfalfa in bloom without serious loss of bees. However, occasional heavy losses have occurred, particularly under high temperature conditions. If applied to alfalfa in bloom, it should be only as a spray, and application should be made during the night or early in the morning when bees are not foraging in the field. Undiluted technical malathion spray (ULV) should not be used around bees.
5. Nematicide.
6. Di-Syston® (disulfoton) and other systemic pesticides used as seed treatments have not caused bee losses.
7. Temik® (aldicarb), although highly toxic to bees as a contact poison, is used only in granular form, and extensive field usage has not caused bee losses.
8. Defoliant.
9. Desiccant.

10. DDT has been withdrawn for most uses in the U.S.A.
11. Field dosages have caused brood damage.

12. The microencapsulated formulation of methyl parathion, known as Penncap-M®, is highly toxic to foraging bees, young hive bees, and brood. Overall, it is 13 times more hazardous to honey bees than the EC (emulsifiable concentrate) formulation. Penncap-M® is too hazardous to be applied to any area at any time when bees are present in the field or within one mile of the area to be treated.
13. Plant growth regulator.
14. Sticker/extender.
15. Nitrification inhibitor.
16. Chemical ripener.
17. Insect growth regulator.
18. Honey bee repellent.

TABLE 2—DATA FOR USE OF HONEY BEE MORTALITY PREDICTOR

NOTE: Bee hazard and residual toxicity information is based on field tests (1950-1980) for dosages normally recommended and utilized as dilute sprays in water on agricultural crops for controlling pest insects and mites. This information is usually applicable for mosquito abatement, forest, rangeland, recreational, and residential treatments but not for low-volume, no water sprays (ULV).

Night applications (darkness until 4 A.M.) will reduce bee kill approximately 50% and reduce overall bee hazard at least one category from sprays applied as early morning applications (daylight to 7 A.M.); applications made after 7 A.M. will increase the overall bee hazard approximately two times, raising the hazard to at least the next higher category.

GROUP I—highly toxic pesticides (LD_{50} = 0.001 to 1.99 µg/bee)

Severe losses may be expected if these pesticides are applied when bees are present at treatment time or within a day thereafter, except as indicated by footnotes. (Listed in order of toxicity; first named is most toxic.)

Pesticide* **(trade and/or common name)**	**Slope, probits**	**Laboratory data** LD_{10}	LD_{50}	LD_{50}	**Field test data Toxicity of residues to bees: †** **No. days**	**Hazard**
tepp[1, 3]	0.68	>0	0.002	0.197	0.5(H)	ML
bioethanomethrin	3.95	0.017	0.035	0.074	0.5(H)	L
resmethrin	4.17	0.031	0.062	0.126	-	-
decamethrin, Decis®	4.88	0.037	0.067	0.124	1.5(H)	NIL
Pay-Off®	3.37	0.035	0.078	0.172	0.5(M)	NIL
chlorpyrifos, Lorsban®, Dursban®	10.17	0.083	0.110	0.147	2-3.5(H)	M-MH
methyl parathion[1],‡	5.13	0.063	0.1 1 1	0.197	0.5(H)	H-VHi:
dieldrin[1]	2.51	0.041	0.133	0.431	1.5-5(H)	H
carbofuran[5], Furadan ®	6.14	0.092	0.149	0.241	3>5(H)	M-H
permethrin[18], Ambush®, Pounce®	5.52	0.094	0.159	0.272	>5(VH)	L

Pesticide* (trade and/or common name)	**Slope, probits**	**Laboratory data** LD10	LD50	LD50	**Field test data** Toxicity of residues to bees: † No. days	Hazard
parathion[1]	4.96	0.098	0.175	0.321	1(H)	H-VH
fenitrothion, Sumithion®	5.75	0.105	0.176	0.294		
dimethoate[1], Cygon®, De-Fend'®	5.84	0.115	0.191	0.316	1-3.5(H)	M-VH
methidathion[1], Supracide®	8.48	0.167	0.237	0.335	2.5(H)	MH
EPN[1]	4.31	0.11 9	0.237	0.469	1.5-3(H)	H
methyl parathion[1],‡, encapsulated, Penncap-M®	5.13	0.136	0.241	0.428		
etrimfos, Ekamet®	2.52	0.082	0.264	0.850	>5(H)	H-VH
aldicarb[1, 5, 7], Temik®	5.00	0.151	0.272	0.491	-	-
mexacarbate, Zectran®	4.87	0.165	0.302	0.553	NIL	NIL§
dicrotophos[1], Bidrin®	15.86	0.253	0.305	0.367	3(H)	H
mevinphos[1, 3], Phosdrin®	7.77	0.209	0.305	0.446	2-4(H)	M-MH
fenthion, Baytex®	6.14	0.197	0.319	0.515	<1-1.5(H)	M-H
fensulfothion[5], Dasanit®	4.78	0.182	0.337	0.624	-	-
aldrin	5.06	0.197	0.352	0.629	-	-
monocrotophos[1], Azodrin®	8.31	0.250	0.357	0.509	-	-
diazinon, Spectracide®	8.03	0.258	0.372	0.538	2-3.5(H)	MH-VH
methiocarb, Mesurol®	3.35	0.154	0.372	0.896	1-2(H)	H
fenvalerate, Pydrin®	4.46	0.211	0.408	0.791	1 (L)	NIL
famphur, Famophos®	4.85	0.225	0.414	0.759	-	-
azinphos-methyl[1], Guthion®	7.43	0.288	0.428	0.637	5(H)	M-VH
bendiocarb, Ficam®	3.28	0.174	0.428	1.05	-	-
naled[3], Dibrom®	6.43	0.406	0.485	0.581	<1-1.5(H)	MH-VH
dichlorvos, DDVP, Vapona®	8:61	0.356	0.501	0.705	-	-
heptachlor[1], Drinox®	5.94	0.320	0.526	0.864	-	-

Field test data

Pesticide* (trade and/or common name)	Slope, probits	Laboratory data LD10	LD50	LD50	Toxicity of residues to bees: † No. days	Hazard
isofenphos, Amaze®, Oftanol®	6.61	0.388	0.606	0.947	-	-
carbosulfan, FMC-35001	4.69	0.362	0.678	1.270	3.5(H)	ML
malathion[4], Cythion®	7.83	0.490	0.726	1.60	1-2(M)	L-MH
azinphos-ethyl, Ethyl Guthion®	7.92	0.661	0.958	1.39	-	-
aminocarb, Matacil®	3.61	0.494	1.12	2.53	-	-
phosmet, Imidan®	3.55	0.495	1.13	2.60	3.5(H)	MH-VH
acephate, Orthene®	8.26	0.841	1.20	1.72	2.5(H)	M-MH
methomyl[5], Lannate®, Nudrin®	2.39	0.374	1.29	4.42	1.5(H)	L-M
propoxur, Baygon®	3.23	0.537	1.34	3.33	-	-
methamidophos, Monitor®	0.61	1.04	1.37	1.81	1 (M)	LM
stirofos, Gardona®	3.96	1.13	1.39	1.72	3.5-5(L)	LM-M
fenamiphos[5], Nemacur®	5.25	0.81	1.43	2.50	-	-
phosphamidon, Dimecron®	2.74	1.15	1.45	1.83	2-5(M)	M-VH
carbaryl, Sevin®	3.04	0.59	1.54	4.05	3-7(H)	M-VH
bufencarb, Bux®	4.95	0.91	1.65	2.99	-	-
pyrazophos, Afugan®	3.48	0.79	1.85	4.32	-	-
arsenicals[1]	1.22	2.47	27.15	299.04	-	-

GROUP II—moderately toxic pesticides (LD_{50} = 2.0 to 10.99 µg/bee)

These can be used in the vicinity of bees if dosage, timing, and method of application are correct, but should not be applied directly on bees in the field or at colonies. (Listed in order of toxicity to honey bees; first named is most toxic).

Pesticide* (trade and/or common name)	Slope, probits	Laboratory data LD10	LD50	LD50	Field test data Toxicity of residues to bees: † No. days	Hazard
temephos, Abate®	2.56	0.44	1.40	4.4Z	0-3(M)	L
demeton[1, 18], Systox®	10.02	1.27	1.71	Z.29	1 (L)	L
trichloronate, Agritox®	4.28	1.00	2.00	3.98	-	-
endrin[1], Endrex®	4.06	0.99	2.04	4.21	1-3(M)	L-M

crotoxyphos, Ciodrin®	15.42	1.92	2.31	2.78	-	-
Pyramat®	5.08	1.47	2.62	4.68	-	-
oxydemeton-methyl, Metasystox-R®	2.49	0.88	2.86	9.35	0.5(L)	M-H
profenofos, Curacon®	5.96	2.11	3.46	5.68	-	-
terbufos, Counter®	3.54	1.78	4.09	9.42	-	-
ethylan, Perthane®	4.01	2.19	4.57	9.57	-	-
ethoprop, Mocap®	4.66	2.95	5.56	10.5	-	
ronnel, Korlan®	2.11	1.39	5.62	22.6	-	-
disulfoton[1, 6, 18], Di-Syston®	1.19	0.52	6.12	72.7	1 (L)	NIL
DDT[1, 10]	4.74	3.33	6.19	11.5	1(L)	L
ethiofencarb, Croneton®	1.99	1.48	6.85	31.6	N I L	N I L
Larvin®, thiodicarb	3.52	3.08	7.08	16.3	NIL	ML
sulprofos, Bolstar®	5.53	4.43	7.2Z	12.3	-	-
endosulfan, Thiodan®	3.15	3.06	7.81	19.9	2(L)	L-MH
fonofos, Dyfonate®	4.87	4.74	8.68	15.9	-	-
chlordane	2.34	2.50	8.80	30.9	-	-
phosalone, Zolone®	3.67	4.02	8.97	20.0	-	-
formetanate hydrochloride, Carzol®	4.21	4.57	9.21	18.6	2(L)	L
phorate[1, 6], Thimet®	1.27	1.00	10.25	104.8	<1-1(L)	L11
temephos, Abate®	2.56	0.44	1.40	4.4Z	0-3(M)	L
oxamyl, Vydate®	5.81	6.17	10.26	17.0	3-4(H)	VH
carbophenothion, Trithion®	2.78	4.51	12.99	37.5	<1 (M)	L
Sevin® SL, carbaryl	1.57	2.07	13.72	>100	6(MH)	H
Pirimor®, pirimicarb	2.87	6.71	18.72	52.2	0.5(L)	L
Sevin® SLR, carbaryl	1.14	1.33	26.53	>100	>6(H)	M
Mavrik®, fluvalinate	1.85	13.36	65.85	324.5	0.5(L)	L-ML

Source: *Toxicity of Pesticides to Honey Bees,* Leaflet 2286, and *Toxicity of Pesticides and Other Agricultural Chemicals to Honey Bees,* Leaflet Z287. (University of California Agricultural Sciences publications).

* See Table 1 for key to numbers 1-18.

†Toxicity of residue to honey bees: No. days = average time in days that residue is toxic to bees; Hazard = severity of the honey bee hazard (L = low; M = moderate, H = high, LM = moderately low, MH = moderately high, VH = very high, NIL = no toxicity and/or no hazard, - = no verified information available). NOTE: Night application (darkness until 4 A.M.) will reduce bee kill at least 50% and reduce bee hazard at least one category from sprays applied as early morning treatments (daylight to 7 A.M.); applications made after 7 A.M. will increase overall bee hazard approximately two times, raising the hazard to at least the next higher category.

‡The encapsulated methyl parathion formulation, Penncap-M®, is highly toxic to foraging bees, young hive bees, and brood. Overall, it is 13 times more toxic to honey bee colonies than the EC

formulation (emulsifiable concentrate). Penncap-M® is too hazardous to be applied to any area at any time when bees are present in the field or within 1 mile of the area to be treated.
§Used only as soil application and/or as granules.
¶When used as soil application of granules: No. days toxic, NIL; Hazard, NIL.

TABLE 3. EXAMPLES OF ANTICIPATED HONEY BEE MORTALITY WHEN A PESTICIDE WITH A LD_{50} VALUE OF 1.0 IS APPLIED AT SELECTED SLOPE VALUES AND INCREASING AND DECREASING DOSAGES

Slope value	Percent mortality at following dosage (lb/acre):									
	0.1	0.25	0.5	0.75	1.0	1.25	1.5	1.75	3.0	10.0
	Below LD_{50}				LD_{50}	Above LD_{50}				
2	3	12	28	42	50	57	64	68	82	97
4	--	1	12	32	50	66	72	82	96	--
6	--	--	2	17	50	76	91	97	--	--
16	--	--	--	3	50	93	--	--	--	--

HONEY BEE MORTALITY PREDICTOR

Instructions

A. Look up the LD_{50} in Table 2 for the pesticide you are going to use. Find this value, or the value closest to it, in 1 below.

B. Read to the right on the same line into **2** and find the dosage, or the closest dosage to the one you intend to actually use in the field.

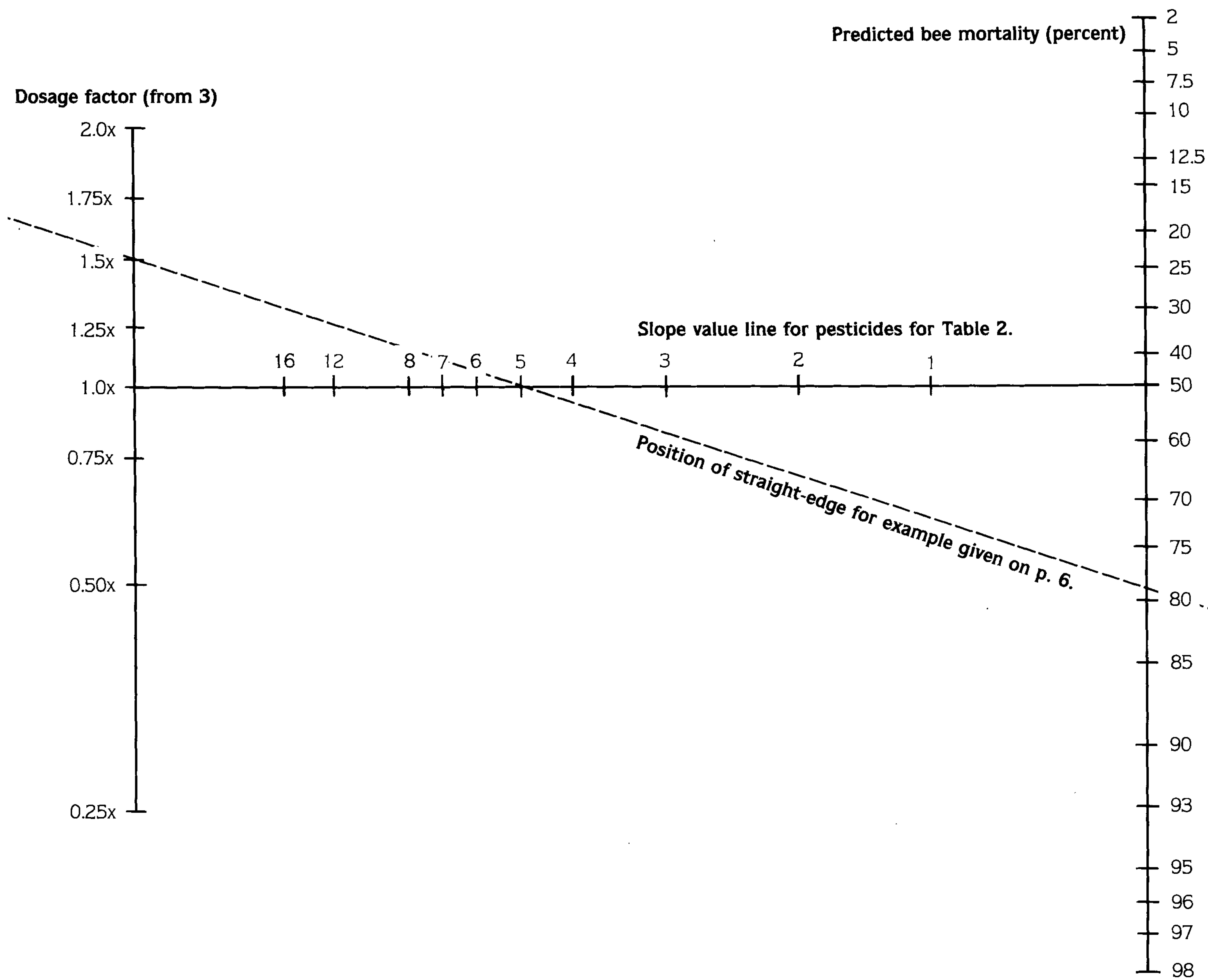
C. From the actual dosage (Box 2), read down the column into Box **3**. This figure represents how much more or less than the LD_{50} your actual dosage is. Find this figure on vertical line of **left** side of the Predictor (**4**).

D. Look up the Slope Value in Table 2 for the pesticide you are going to use, and locate it on the Slope Value line on **4**.

E. Use a ruler or other straight-edge (**4**) to connect the point on the Dosage Factor line to the point on the Slope Value line. Extend the straight-edge to intersect the vertical line on the **right** in the Predictor. At the point of intersection, you can read the predicted percent mortality of honey bees in the field for the type and dosage of pesticide you intend to use.

NOTE: By rotating your straight-edge and working backwards, you can determine how much to lower the dosage to avoid serious bee kill.

1. LD_{50} of pesticide lb/acre (a.i.)	**2. Actual dosage you intend to use in pounds of active ingredient per acre (a.i.).**							
0.175	0.04	0.09	0.13	0.175	0.22	0.26	0.31	0.35
0.30	0.08	0.15	0.23	0.30	0.38	0.45	0.53	0.60
0.40	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
0.50	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.0
0.70	0.18	0.35	0.53	0.70	0.88	1.00	1.23	1.4
1.00	0.25	0.5	0.75	1.00	1.25	1.50	1.75	2.0
1.25	0.31	0.63	0.94	1.25	1.56	1.88	2.19	2.5
1.50	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.0
2.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
2.5	0.63	1.25	1.88	2.5	3.13	3.8	4.4	5.0
3.0	0.75	1.5	2.25	3.0	3.75	4.5	5.25	6.0
4.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
5.0	1.25	2.5	3.8	5.0	6.3	7.5	8.8	10.0
6.0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0
7.5	1.9	3.8	5.6	7.5	9.4	11.0	13.0	15.0
10.0	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0
	3. Factor representing how much more or less than the LD_{50} you intend to use.							
	0.25x	0.5X	0.75X	1.0X	1.25x	1.5x	1.75x	2.0x


Dosage factor (from 3)
2.0x
1.75x
1.5x
1.25x
1.0x
0.75x
0.50x
0.25x
Slope value line for pesticides for Table 2.
16
12
8
7
6
5
4
3
2
1
Position of straight-edge for example given on p. 6.
Predicted bee mortality (percent)
2
5
7.5
10
12.5
15
20
25
30
40
50
60
70
75
80
85
90
93
95
96
97
98

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