METHOMYL INSECTICIDE AND DOMESTICATED POLLINATORS[1]

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ABSTRACT

Susceptibility to methomyl sprays was greatest for the alfalfa leafcutting bee, *Megachile rotundata* (F.); least for the honey bee, *Apis mellifera* L.; and intermediate for the alkali bee, *Nomia melanderi* Cockerell. Methomyl at 1.12 kg (AI)/ha had low residual hazard to honey bees, and at 0.6 kg (AI)/ha it had low residual hazard to leafcutting and aklaki bees after one day. Field tests of methomyl on pollen-shedding corn, blooming red raspberry, and blooming blueberry resulted in reduced bee visitation and low adult bee mortality.

Insecta, Bees, Pollinators, methomyl

INTRODUCTION

Methomyl is a carbamate insecticide available in wettable powder, dust, and liquid formulations. It kills as a contact or stomach poison and is registered for insect control on a large number of agricultural crops.

Bee poisoning or the killing of beneficial bees from pesticides is a serious problem for beekeepers in most parts of the world (Johansen and Mayer, 1989). For 35 years we have evaluated pesticides for their effects on bees and developed information to reduce bee poisoning (Mayer and Johansen, 1988).

This paper reports the results of research concerning the effects of methomyl on the honey bee, *Apis mellifera* L., alkali bee, *Nomia melanderia* Cockerell, and alfalfa leafcutting bee, *Megachile rotundata* (F.). Also reported are the insecticide's effects on honey bees when applied to pollen-shedding corn, blooming red raspberry, and blooming blueberry.

MATERIALS AND METHODS

Small-scale Bioassays. Tests were conducted with different formulations and rates of methomyl on honey bees, alkali bees, and alfalfa leafcutting bees, from 1968 through 1987. Methomyl was applied to 0.004-ha plots of alfalfa with a Solo® backpack boom sprayer, using 1758 g/cm^2 pressure and 234 liters of water/ha. Treatments of field-weathered methomyl residues were replicated four times with four foliage samples per treatment and time interval. Samples consisting of about 500 cm^2 of foliage taken from the upper 15-cm portions of plants were placed in each plastic petri dish (15 cm diameter) whose tops and bottoms were separated by a wire screen (6.7 meshes/ cm) insert (45 cm long and 5 cm wide). The same procedure was used in the following tests: residual toxicity of methomyl combined with the stickers Adhere® and Plyac (both United Agr. Products, P. O. Box 1286, Greeley, CO 80632).

The residual toxicity of methomyl combined with the formamidine insecticide chlordimeform also was tested. Residual toxicity of repeated applications (4 times) of methomyl also was evaluated as was the effect of methomyl on alfalfa leafcutting bees of different ages. In one test, treated foliage was held in the lab in the dark at 18 or 29°C, or outdoors in 18-35°C variable day-night temperatures and daily sunlight. In still another test, 50 honey bees were placed in each of 4 cages as described above and methomyl was applied directly onto the bees.

FOOTNOTES

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Worker honey bees were obtained from colonies and anesthetized with CO_2. Prepupae of leafcutting bees and alkali bees, in leaf piece cells and soil cores, respectively, were incubated at 29-31°C and 60% RH. Emergent adults were trapped in canisters fitted with screen funnels and chilled to facilitate handling. Residue test exposures were replicated four times by caging 60 - 75 worker honey bees, 25 - 40 leafcutting bees, or 15 - 20 alkali bees with each of four foliage samples per treatment and time interval. Bees were maintained in cages at 29°C, 60%, RH and fed 50% sucrose solution (1:1) in a cotton wad (5 by 5 cm). Bee mortality was determined after 24 h. Abbott's formula (Abbott 1925) was used to correct for mortality occurring in the untreated check. Data were analyzed using analysis of variance (ANOVA) techniques with mean separation by Duncan's Multiple Range Test (Duncan, 1951).

Field Tests -- Corn. In 1973 methomyl was tested for bee toxicity on pollen-shedding 'Jubilee' sweet corn in a 4.5-ha field and in 1983 in a 55-ha field near Prosser, WA. In 1973, methomyl 90% soluble powder (SP) was applied by airplane before 0700 h on 3 Sept, using 0.5 kg (AI)/ha in 45 liters of water. A 9-ha field 1 km away served as the untreated check. In 1983, methomyl 90% wettable powder (WP) was applied by helicopter before 0700 h on 2, 6, 10 and 14 Sept, using 0.5 kg (AI)/ha in 20 liters of water. A 55-ha field 1 km away served as the untreated check.

Honey bee colonies with Todd dead bee traps (2 in 1973; 6 in 1983) were located adjacent to the fields 3 days before the first application. In 1973 and 1983, the number of dead honey bees was recorded daily before and after the applications. In 1983, 25 dead bees from each colony were examined during each sample for tongues fully extended, and the data were recorded. Also in 1983, data on the number of corn pollen collectors per 25 foragers per colony for a total of 150 bees per sample were recorded. Colony conditions were evaluated before and after each application and at the conclusion of each test.

Field Tests -- Raspberries. In 1983, methomyl was tested for bee toxicity on blooming red raspberry near Vancouver, WA. Methomyl 90 SP was applied at 0.5 kg (AI)/ha and at 1.0 kg (AI)/ha to separate 0.02-ha plots of 'Meeker' red raspberry, and a separate 0.02-ha plot was left untreated. Applications were made on 26 July at 2000 h by ground equipment with a hooded-boom sprayer. Two weeks before the application, four honey bee colonies were placed near the center of the field. Bee numbers and foraging behavior were assessed in the plots during mid-afternoon of the first day after application and on days 2, 3, and 6 following application. The number of honey bees foraging on 14 meters (5 replications) of row were counted in each plot on each date.

On 27 July, at 0600 h, 200 blooms in each plot were covered with white paper bags, to exclude bees so that nectar samples could be taken. Three kinds of samples were taken from each plot: (1) 200 flowers that were rinsed in 200 ml of distilled water, (2) the rinse water drained from the flowers, and (3) 20 l of floral nectar collected from each of 20 flowers. Samples were taken at 0800 h and 1200 h, frozen, and sent to E. I. DuPont de Nemours and Company chemists for analysis of methomyl residues. We consistently obtained 15-20 µliters of nectar per flower (av. 17) with 50% sugar content. Data were analyzed using ANOVA techniques with mean separation by Duncan's Multiple Range Test (Duncan, 1951).

Field Tests -- Blueberry. Methomyl 1.8 soluble liquid (LS) (1.0 kg (AI)/ha) was applied in 936 liters of mixed spray per ha at 1000 h on 16 April 1987. Biofilm wetting agent at the rate of 473 ml per 379 liters was added. The plots consisted of 9 x 8 m of 'Berkeley' blueberry in full bloom adjacent to six honey bee colonies. The weather was cool and overcast at 13°C with a light northwest wind at 11-13 kph. A few bumble bees were working in the blueberries, but no honey bees. Twenty white paper bags were placed on blooming tips in the treated plots and on tips in the check plots (33 m west and 33 m east) at 1230 h. The temperature increased to 14°C by 1600 h, but light rains started at 1630 h.

April 17 was cool and rainy and no honey bees were working. Nectar samples were extracted from the bagged blooms using a micropipet. There was an average of 10.2 µliters of nectar per flower with an average 24% sugar content. On 18 April the weather was still cloudy with occasional light rains, but was suitable at times to observe honey bee activity. The number of honey bees foraging on 15 meters of row was determined for each plot.

RESULTS

Small-scale Bioassays. Table 1 presents the means of bioassay tests done from 1968 through 1973. The mortality sequence for the three species was typical in that alfalfa leafcutting bees were most susceptible, alkali bees were intermediate in susceptibility, and honey bees least susceptible to methomyl. Bee susceptibility to an insecticide is a function of size or surface/volume ratio which is related to chance adherence of residues to the body of a forager (Johansen et al., 1983). The mortality of bees in 24 h continuous contact with treated foliage samples decreased as the age of residues increased. The 2% dust formulation was more hazardous than other formulations, causing 46 - 98% mortality one day after application. For the other formulations, the rates of 0.6 kg(AI)/ha or lower caused less than 25% mortality of honey bees 3 h after application. The rate of 1.12 kg(AI)/ha caused 27% or lower mortality after 8 h. Methomyl 1.8 LS (0.3 kg/ha) and methomyl 90 WP (0.6 and 1.12 kg/ha) applied directly to honey bees caused 100% mortality.

Adding the sticker Adhere® significantly reduced mortality for all three bee species. Adding Plyac® did not always reduce bee mortality. Mayer *et al.* (1987) showed that adding the sticker Bond® to methomyl and Johansen (1972) showed that adding Evanol to methomyl resulted in reduced bee mortality.

Repeated applications of methomyl at 5-day intervals caused increasing mortality with successive treatments (Table 3). For example, with honey bees, mortality for each application was 19, 28, 41, and 63%.

Adding chlordimeform 97% soluble powder (SP), a material essentially non-hazardous to bees (Mayer & Johansen, 1988), at 0.3 kg/ha to methomyl 1.8 LS at 0.3 kg/ha, resulted in a synergistic effect that increased honey bee mortality from 2 h residues by 72%.

Methomyl 1.8 LS (0.3 kg/ha) caused 51% mortality in 4-wk-old leafcutting bees but only 8% in 1-2-day-old bees. In general, older leafcutting bees that have been nesting for 3 or more weeks have increased susceptibility to poisoning by most insecticides (Mayer & Johansen, 1988).

Table 1.

Mortality of alkali bees (AB), alfalfa leafcutting bees (LB), and honey bees (HB), exposed to different age residues of methomyl applied to field plots of alfalfa. Pullman, WA, 1968-1973.

Rate Methomyl Treatment[a]	(kg(AI) /ha)	24-h mortality (%) of bees caged with treated foliage at indicated age of residues										
		AB				LB				HB		
		3 h	8 h	24 h	72 h	3 h	8 h	24 h	72 h	3 h	8 h	24 h
1.8 LS	0.3	3	0	-	-	13	5	0	-	2	0	0
1.8 LS	0.6	24	0	-	-	23	6	2	-	23	0	0
1.8 LS	1.12	61	38	19	-	86	59	65	-	43	10	3
25 WP	0.6	-	-	-	-	-	-	-	-	20	5	1
90 WP	0.6	47	8	-	-	48	13	4	-	18	5	2
90 WP	1.12	96	64	40	16	83	73	60	13	92	27	1
90 SP	0.3	0	2	-	-	11	3	4	-	4	3	0
90 SP	0.5	-	-	-	-	-	-	-	-	26	0	0
90 SP	0.6	-	-	-	-	-	-	-	-	18	7	0
90 SP	1.12	-	-	-	-	-	-	-	-	44	21	0
2% dust	0.6	-	-	-	-	100	100	100	-	100	75	46
2% dust	1.12	100	90	84	-	100	100	88	-	100	98	98

[a]LS, liquid; WP, wettable powder; SP, soluble powder

Table 2.

Mortality of alkali bees (AB), alfalfa leafcutting bees (LB), and honey bees (HB), exposed to different age residues of methomyl applied to field plots of alfalfa. Prosser, WA, 1987.

Treatment	Rate (kg (AI)/ha)	24-h mortality (%) of bees caged with treated foliage at indicated time after treatment						
		AB		LB		HB		
		2h	8h	2h	8h	2h	4h	8h
Methomyl 90 WP	1.0	83a	78a	86a	50a	69a	-	36a
Methomyl 90 WP + Adhere	1.0 + 118 ml	34b	26b	60b	31b	18b	-	13b
Methomyl 90 WP + Plyac	1.0 + 118 ml	43b	39b	60b	63a	21b	-	31a

Means within a column and year followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

Table 3.

Mortality of alkali bees (AB), alfalfa leafcutting bees (LB), and honey bees (HB), exposed to residues of methomyl 1.8 LS (0.5 kg (AI)/ha) from successive applications to plots of alfalfa. Pullman, WA, 1976.

Treatment[a/]	24-h mortality (%) of bees caged with treated foliage at indicated time after treatment			
	AB	LB	HB	
	2 h	2 h	2 h	8 h
1st application	9 a	36 a	19 a	4 a
2nd application	22 b	52 b	28 a	11 b
3rd application	42 c	54 b	41 b	16 b
4th application	89 d	55 b	62 c	62 c

Means within a column and followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

[a/] Application dates: 12, 17, 22, 27 June.

The effects of temperature and sunlight on methomyl activity against honey bees are shown in Table 4. Two- and 8-h residues held at 18°C and 29°C in constant dark caused significantly less mortality than the residues held in variable day-night temperatures and exposed to sunlight. This is the reverse of expected results (Johansen *et al.*, 1983). Perhaps sunlight and heat caused the methomyl to break down to a more toxic product.

Field Tests -- Corn. In 1973, the Todd trap catches for the first 24 h after application averaged 13 bees next to the treated field and 20 in check colonies 1 km distant. Methomyl applied to pollen-shedding corn in 1983 resulted in no abnormal loss or perhaps a low kill (Table 5). Use of Todd dead bee traps on honey bee colonies has shown that up to 100 dead bees per day is a normal die-off, 200-400 is a low kill, 500-900 is a moderate kill, and 1000 or more is a high kill (Mayer & Johansen, 1983). Bees dying with tongues extended is often a sign

Table 4.

Mortality of honey bees exposed to different age residues of methomyl 90 SP applied to field plots of alfalfa at the rate of 1.0 kg (AI)/ha. Residues were held under different environmental conditions before bee exposure. Prosser, WA, 1987.

Treatment	24-h mortality (%) of bees caged with treated foliage collected at indicated times after treatment		
	2 h	8 h	24 h
18°C - constant dark	28a	9a	0a
29°C - constant dark	49a	6a	1a
18-35°C - outdoors, daily sunlight	77b	36b	1a

Means within a column and followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

Table 5.

Effect of methomyl applied to sweet corn at 0.5 kg (AI)/ha on honey bee foragers returning to the hive with corn pollen and on honey bee mortality, based on Todd dead bee traps, in colonies placed adjacent to treated sweet corn fields. Prosser, WA, 1983.

Date		Mean No. dead bees/colony/day (% with tongues fully extended)		% bees bringing in corn pollen**
Aug.	29	25	(41)	73
	30	12	(44)	74
	31	28	(42)	71
Sept.	1	10	(43)	65
	2*	74	(65)	22
	3	170	(61)	37
	4	137	(64)	50
	5	100	(62)	79
	6*	104	(54)	36
	7	66	(55)	51
	8	260	(52)	--
	9	77	(44)	55
	10*	38	(42)	40
	11	250	(50)	41
	12	109	(57)	32
	13	53	(38)	51
	14*	83	(36)	45
	15	214	(42)	31
	16	27		25
	17	42		21

* Applied by aircraft at 0600 h on these dates.

**Sample size-150 bees on each date.

of bee poisoning, especially with organophosphates (Johansen, 1984), but with methomyl there was no difference in the number of dead bees with tongues extended. Bees collecting corn pollen were reduced by about 30% for one day after application. There were no reductions in bee populations or brood in the colonies at the end of the test.

Field Tests -- Raspberry. As soon as bees began foraging raspberry blooms the day after application their behavior changed. They removed nectar, backed away, and soon were avoiding treated blooms. Sometimes they would move onto a leaf to groom themselves.

Table 6.
Effect of methomyl applied on 26 July at 2000 h on honey bees foraging in blooming red raspberries. Vancouver, WA, 1983.

	Mean Number foraging bees/14 m of row			
Kg (AI)/ha	27 July	28 July	29 July	1 August
0.5	9 *	6 *	21 *	64 ns
1.0	4 *	1 *	15 *	78 ns
Untreated check	56	61	69	68 ns

*Values are Significantly different (P = 0.05) from untreated check value in respective column. Pooled t test.

Within a short time, most bees drifted along the rows to the check block. Methomyl was strongly repellent to the bees for 2 days but less so on the third day. Bees resumed normal activity by the 6th day (Table 6).

Most methomyl residues detected from flower surfaces (water wash), flower interiors (homogenized flowers), and nectar showed some degradation between the 0800 h and 1200 h samplings. However, only surface residues were reduced greatly during the 4-h period. The minimal amounts of residue detect-ed in the untreated check plot samples were a true reflection of the spray application. The hooded boom sprayer was driven through all three adjacent plot rows during each pass because of space limitations. No doubt there was a minimal contamination of the check plot during this process (Table 7).

Table 7.
Residues of methomyl detected in red raspberry flower and nectar samples 27 July. Vancouver, WA, 1983.

	Methomyl residues (ppm)					
	0800 h			1200 h		
Kg (AI)/ha	Flower surface	Homogenized flowers	Nectar	Flower surface	Homogenized flowers	Nectar
0.5	2.0 a	8.1 a	3.4 a	0.27 a	2.1 a	2.8 a
1.0	2.6 a	9.0 a	6.9 b	0.91 b	9.3 b	5.3 b
Untreated check	0.05b	0.29b	<0.02c	0.04 c	0.28c	<0.02c

Means within a column and followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

Field Tests -- Blueberry. Honey bees started to enter the blueberry field by 0930 h, but there were too few to make useful counts in the plots. After 2 days of inactivity, bees started foraging in fair numbers by 1100 h, even though the temperature was only 12°C. The same kind of response, which was first observed with methomyl in red raspberry investigations in

Table 8.
Effect of methomyl applied at 2000 h on 16 April (1.0 kg[AI]/ha) on honey bee behavior in blooming blueberries. Cornelius, OR, 1987.

Time	Temp	Mean number foraging bees/15 m of row on 18 April	
1100	12°C	treated	0(8)[a/]
		check	20(0)
1200	10°C	treated	0(1)
		check	17(0)
1400	11°C	treated	0(2)
		check	18(0)

[a/]Figures in parentheses are counts of bees that alighted on flowers or probed around the bases, but never inserted their heads into the flower cups.

1983, was again recorded (Table 8). In this case, the honey bees probed around the base of the flowers externally and then flew off to untreated portions of the field without again landing on a treated bloom. Apparently they were able to detect the chemical and avoid it after the initial approach. In contrast, bees foraging the untreated check blooms inserted their heads into the flower cups in normal foraging fashion.

DISCUSSION

It is evident from these studies that methomyl is toxic in varying degrees to the bee species studied, and that methomyl applications affect bee behavior. In laboratory tests of direct toxicity, both 0.01 and 1% concentrations of methomyl caused 100% mortality of honey bees (Harris and Svec, 1969). The topical LD_{50} for honey bees is reported as 1.29 µg per bee (10.1 ppm) (Atkins *et al.*, 1981) or 0.068 µg per bee (Mansour & Al-Jalili, 1985).

Anderson & Wojtas (1986) found methomyl residues, along with other insecticides, in dead bees obtained from beekeepers but were not able to determine if it was methomyl that killed the bees. Flaherty et al. (1977) observed that early morning and night applications of methomyl to citrus bloom caused little harm to honey bees. Atkins *et al.* (1981) reported that methomyl was highly toxic to honey bees present in the field during applications, though the field hazard was low with evening applications. In our studies, the residual degradation time (RT) in hours required to bring bee mortality down to 25% (RT 25) in cage test exposures to field-weathered spray deposits applied at 0.3 kg (AI)/ha was < 2 h. At 0.5 kg (AI) ha the RT 25 was 2 h, and at 1.0 kg (AI)/ha it was 6 h. However, with the dust formulation the RT 25 was > 1 day. Materials with an RT 25 of 8 h or less are useful in terms of bee safety if applied during the late evening or at night.

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