INTEGRATED CONTROL OF APPLE PESTS IN NEW ZEALAND 13. SELECTIVE INSECT CONTROL USING DIFLUBENZURON AND *BACILLUS THURINGIENSIS*

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Summary

Diflubenzuron was shown over three seasons to be a promising agent for selective control of apple insect pests in Nelson. In the final season (1977-78) diflubenzuron was combined with *Bacillus thuringiensis* particularly for control of leafrollers (*Epiphyas postvittana, Planotortrix excessana* and *Ctenopseustis obliquana*). Codling moth (*Laspeyresia pomonella*) control was excellent in all seasons through the ovicidal and larvicidal action of diflubenzuron. Leafroller damage was reduced significantly by the treatments each season and was very low on the treated 'Delicious' trees in 1977-78. However, leafroller damage on the treated 'Sturmer Pippin' trees in 1977-78 reached 5%. San Jose scale (*Quadraspidiotus perniciosus*) and mealy bug (Pseudococcidae) infestation of the fruit was not reduced by the treatments. Diflubenzuron appeared non-toxic to *Typhlodromus pyri* the most important predator of European red mite (*Panonychus ulmi*) but toxic to insect predators of this pest. Woolly aphid (*Eriosoma lanigerum*) increased to damaging levels under diflubenzuron despite survival of the parasite *Aphelinus mali*. While suitable for use in orchards growing fruit for local consumption further work is needed on rates and methods of application of diflubenzuron/*B. thuringiensis* to determine their suitability for use on export crops.

INTRODUCTION

Prior to the introduction of broad-spectrum insecticides to apple orchards European red mite had the status of a minor pest due to the actions of its natural enemies. In New Zealand the most important of these are the phytoseiid *Typhlodromus pyri*, the coccinellid *Stethorus bifidus* and the mirid *Sejanus albisignata* (Collyer 1978). Destruction of these natural enemies by insecticides and the ability of European red mite to develop resistance to acaricides has contributed to the major status of this pest today.

Although integrated mite control using insecticide-resistant *T. pyri* offers a partial solution to the problems of mites in orchards (Wearing *et al* 1978), this technique depends on the continued use of organophosphates for insect control. If these chemicals were to be displaced, new strains of *T. pyri* would be needed with resistance to the new insecticides. The long term solution to pest control problems in orchards lies, therefore, in selective insect control which permits maximum use of biological control of all pests.

Integrated Control

In a long term study the selective insecticide ryania failed to provide economic control of codling moth and leafrollers (notably *Epiphyas postvittana*) but permitted natural control of European red mite and woolly aphid (Collyer and Geldermalsen 1975, Wearing 1978). The present paper describes experiments from 1975-78 in selective insect control using diflubenzuron alone and in combination with *Bacillus thuringiensis*. The compatibility of these materials was demonstrated by Morris (1977). Diflubenzuron has been shown to inhibit chitin synthesis in insects (Post and Vincent 1973).

METHOD

The experiments were conducted at the DSIR Appleby Research Orchard, Nelson.

Experimental design

In 1975-76 diflubenzuron (40 g/100 litres) was applied to six replicates of single tree plots of the apple cultivar 'Delicious' using portable high-volume equipment and orchard guns at a rate of 4000 litres/ha. Six unsprayed trees served as 'controls'. In 1976-77 a plot of 50 'Delicious' trees was treated with diflubenzuron (25 g/100 litres, first two applications, or 20 g/100 litres) by air-blast machine set for dilute application at 3000 litres/ha. An adjacent block of 50 trees served as an unsprayed 'control'. The same block of 100 'Delicious' trees was used in 1977-78 but the split between unsprayed 'control' and sprayed trees was at 90° to that of the previous season. The insecticide treatment in 1977-78 was diflubenzuron (37.5 g/100 litres) plus *Bacillus thuringiensis* (Dipel) (150 g/100 litres) by air-blast machine set for concentrate application at 750-1000 litres/ha. This treatment was also applied to 45 'Sturmer Pippin' trees while an adjacent block of 38 trees of this cultivar served as an unsprayed 'control'. In both 1976-77 and 1977-78 six trees were designated as sample trees (for insect pests) from within each treatment and cultivar.

All the experimental plots received a fungicide programme of dodine, colloidal sulphur and thiram.

Sampling

Insect damage was recorded on all the windfalls from the sample trees. At harvest all pest damage was recorded on the fruit of two sample cases from each sample tree using standard methods (Collyer and Geldermalsen 1975). To estimate the mortality of codling moth eggs and first instar larvae, random samples of fruit clusters in each treatment were examined for eggs and associated fruit entries in January 1976 (100-150 clusters per treatment) and 1977 (50 clusters per treatment). Details of the sampling method are presented by Wearing (1978).

The effects of the treatments on European red mite and *T. pyri* were assessed each season from random samples of 50 leaves per treatment taken every two weeks. The mites were removed from the leaves using a mite brushing machine (Leedom Engineering Co. Ltd, U.S.A.) and the active stages of all mites and the eggs of *T. pyri* were recorded.

RESULTS

Codling moth

The egg samples in 1975-76 and 1976-77 showed that diflubenzuron prevented the hatching of fertile eggs of codling moth (Table 1).

The occurrence of inviable eggs on unsprayed branches close to the sprayed trees indicated that spray drift increased inviability of the eggs on the control trees in 1975-76 (Table 1). The survival of eggs in the

TABLE 1: Effect of diflubenzuron on the mortality of codling moth eggs and first instar larvae.

Season	Treatment	Eggs No.	Eggs Infertile (%)	Eggs Inviable (%)	Mortality of first instar larvae before fruit entry (%)
1975-76	control	87	0	21.8	7.4
	diflubenzuron	78	0	89.7***	100
1976-77	control	120	0	6.7	10.7
	diflubenzuron	84	0	97.6***	-*

*** Significantly higher than in the control treatment $p < 0.001$.

* Larval mortality could not be estimated accurately due to the high egg mortality.

diflubenzuron treatment was so low that accurate assessment of the mortality of first instar larvae was not possible. However, the data from 1975-76 suggested that diflubenzuron prevented fruit entry by the few surviving neonate larvae.

This excellent control of codling moth by diflubenzuron was confirmed by the harvest (Table 2) and windfall records. Total damage to the harvested 'Delicious' fruit by codling moth in the diflubenzuron treatments was well below 0.5% (with no deep entries) in each season despite the presence of a very dense codling moth population on the trees (as shown by egg counts) and on the neighbouring 'control' trees (Table 2). In 1976, 1977 and 1978 respectively only two, zero and two fruits among 1489, 250 and 1026 windfalls (total of six 'Delicious' trees) were damaged superficially by codling moth in the diflubenzuron treatments. This contrasts with 268, 792 and 359 damaged fruits (mainly deep entries) out of 1579, 990 and 1251 windfalls in the 'control' treatments in the same three seasons.

The amount of diflubenzuron applied per hectare was decreased each year but without loss of codling moth control on 'Delicious'. However, hatched eggs were encountered on harvested fruit in 1978 suggesting reduced ovicidal action in that season (0.30-0.37 kg/ha). This was confirmed by the codling moth damage to 'Sturmer Pippin' (Table 2) where even a few deep entries and 2.4% superficial entries occurred in the diflubenzuron treatment. Windfall fruits were also damaged. Good spray coverage is difficult on the short-stemmed and tightly-clustered fruits of 'Sturmer Pippin' and the results indicate that a greater quantity of diflubenzuron per hectare is required for codling moth control on this variety.

Leafrollers

Diflubenzuron was less successful in preventing fruit damage by leafrollers than that by codling moth. Nevertheless, leafroller damage at harvest was significantly reduced by this treatment compared with the 'control' in both 1976 and 1977 (Table 2). In 1977 even leafroller entry to the calyx of fruit was reduced by diflubenzuron so that at harvest only 0.5% of fruits carried live larvae compared with 8.9% of fruits from the 'control' trees. Similar differences between the two treatments were evident in the damage to the windfall fruits.

TABLE 2: Mean percentages of damage to harvested fruits on two sample cases from each of six trees per treatment.

Season, Cultivar and Treatment	No. cases per tree	No. fruit per case	Clean of LR and CM	Codling moth (CM) entries Alive	Dead	Leafroller (LR) <5mm	>5mm	Calyx†	Red mite eggs+	Woolly aphid	San José scale	Noctuid	Mealy bug
1976 Delicious													
control	5.5	147.5	80.0	7.0	3.7	7.3	5.7	2.0	15.3	2.4	0.8	1.6	0.2
diflubenzuron	12.7	144.5	93.9**	0.0***	0.05**	3.0**	2.0**	1.0	47.1*	13.4**	0.1	1.0	0.1
1977 Delicious													
control	2.7	130.0	36.9	38.0	11.4	8.1	11.4	6.5	3.3	6.4	0.1	3.5	0.7
diflubenzuron	4.2	128.0	94.5***	0.0***	0.3***	2.0***	1.7***	1.3***	40.2***	10.2	0.6	4.2	0.0
1978 Delicious													
control	-	189.2	75.6	8.4	5.6	4.4	7.5	0.8	13.5	0.3	22.3	1.3	1.1
diflubenzuron and 'Dipel'	-	200.6	97.9***	0.0***	0.2***	0.7***	1.0***	0.2*	16.0	1.4**	16.2	0.5	1.7
1978 Sturmer Pippin													
control	-	224.1	64.5	17.2	7.8	4.6	7.7	1.0	6.3	0.4	29.8	1.7	1.2
diflubenzuron and 'Dipel'	-	175.2	90.9***	0.7***	2.4***	3.5*	2.4*	0.4*	4.2	1.0	42.5	0.3	2.2

\+ Fruits with >20 eggs.
* Significantly different from control at $p < 0.05$, $**p < 0.01$, $***p < 0.001$ for arc/sin transformed data.
† Percentage of fruit with leafroller larval entry at the calyx.

Treatment dates were:
1975-76 5 and 18 November, 3, 17 and 30 December, 12 and 27 January, 10 and 23 February, 9 March.
1976-77 18 November, 1, 15 and 30 December, 13 and 28 January, 14 and 28 February.
1977-78 4 and 24 November, 7 and 21 December, 5 and 17 January, 1 and 17 February, 3 March (Sturmer only).

Integrated Control

It was hoped that the addition of 'Dipel' to diflubenzuron would provide a synergistic increase in the efficiency of the two materials in controlling leafrollers. Harvest data in 1978 provided no evidence of this, although leafroller damage to 'Delicious' was markedly reduced compared with that in the control treatment (Table 2). The low quantity of diflubenzuron applied per hectare in 1977-78 may have partially offset the benefit of adding 'Dipel'. 0.2% of 'Delicious' fruit carried live leafroller larvae at harvest in the diflubenzuron/'Dipel' treatment (*cf.* 1.5% in the 'control' treatment).

Similar levels of live larvae occurred on the sprayed 'Sturmer Pippin' trees but protection of the fruit from damage was less than that achieved on 'Delicious' (Table 2). Spray penetration of the tight-clustered 'Sturmer Pippin' fruits was apparently insufficient using concentrate spraying at only 0.37 kg diflubenzuron + 1.5 kg 'Dipel' per hectare.

Other insect pests

By January 1976 observations indicated that the woolly aphid population in the diflubenzuron treatment was increasing relative to that in the 'control' and this was confirmed at harvest (Table 2). A similar effect occurred in 1977 and 1978 (Table 2). Parasitism of the woolly aphid colonies by *Aphelinus mali* was common in both treatments and years but many dead hemerobiid predators were found in association with the dense colonies in the diflubenzuron treatments.

Damage to the fruit by noctuid larvae, which occurred mainly soon after fruit set, did not differ significantly between the treatments in any year (Table 2). San José scale and mealy bug were not reduced on the fruit by diflubenzuron/'Dipel' in 1977-78, the only season when these pests reached levels satisfactory for the assessment of control (Table 2).

European red mite and T. pyri

In the 1975-76 season monitoring of the mite and predator populations on the leaves suggested that diflubenzuron had little disruptive influence on the natural control of European red mite (Table 3).

The numbers of both European red mite and *T. pyri* increased more rapidly on the trees sprayed with diflubenzuron when compared with those on the 'control' trees but peak numbers of European red mite were similar on the two treatments. However, a sample of leaves from each of the twelve trees on 17 March 1976 showed that European red mite numbers were low on five of the control trees (0.0, 0.4, 1.7, 8.0 mites/leaf) and high on just one tree (45.8 mites/leaf). This tree was surrounded by diflubenzuron-treated trees which carried more consistently high numbers of red mite (34.9, 3.7, 10.1, 6.3, 6.6, 8.2 mites/leaf).

Mite monitoring in 1976/77 confirmed that diflubenzuron disrupted natural control of European red mite but there was again little evidence of toxicity of the chemical to *T. pyri* (Tables 2 and 4).

Many *T. pyri* survived the diflubenzuron treatment but the predator did not reach such high densities on the treated trees as those on the 'control' trees. There was no evidence of reduced oviposition by *T. pyri* as a result of the spraying. A total of 102 eggs were recorded over the season in samples from the unsprayed trees compared with 95 eggs in samples from the sprayed trees.

The same block of 'Delicious' trees was used in 1977-78 as in the 1976-77 season and the carry-over of European red mite resulted in high spring populations in both the sprayed and 'control' treatments. A miticide spray (cyhexatin 13 g/100 litres) applied on 14 December 1977 was effective, in combination with *T. pyri*, in reducing mite numbers

TABLE 3: Mite populations on delicious apple trees treated with diflubenzuron applied by hand, 1975-76.

Treatment	Mite species	Average no. of mites per leaf 2/12	16/12	30/12	12/1	27/1	9/2	23/2	8/3	17/3
control	*P. ulmi*	0.0	0.4	0.4	1.4	2.0	6.9	9.6	23.1	9.3
	T. pyri	0.04	0.10	0.12	0.16	0.16	0.14	0.18	0.52	0.77
diflubenzuron 400 g/100 litres	*P. ulmi*	0.0	0.5	0.3	2.2	3.7	9.3	18.7	22.0	11.6
	T. pyri	0.00	0.08	0.16	0.10	0.28	0.18	1.04	1.44	1.54

TABLE 4: Mite populations on delicious apple trees treated with diflubenzuron applied by air-blast sprayer, 1976-77.

Treatment	Mite species	Average no. of mites per leaf 24/11	6/12	20/12	4/1	17/1	1/2	14/2	28/2	14/3	29/3
control	*P. ulmi*	0.2	0.4	1.1	0.7	2.5	1.4	2.6	2.5	3.3	2.3
	T. pyri	0.44	0.28	0.58	1.40	0.92	1.98	2.94	2.54	1.60	1.48
diflubenzuron 20-25 g/100 litres	*P. ulmi*	0.2	0.4	1.4	1.1	4.6	3.1	7.4	8.9	15.7	14.1
	T. pyri	0.48	0.50	0.32	0.68	0.74	1.48	1.10	1.16	1.84	1.14

TABLE 5: Mite populations on delicious apple trees treated with diflubenzuron and 'Dipel' applied by air-blast sprayer, 1977-78.

Treatment (g/100 litres)**	Mite species	Average no. of mites per leaf 31/10	14/11	28/11	6/12	14/12	19/12*	29/12	11/1	25/1	6/2	21/2	7/3
control	*P. ulmi*	2.4	1.1	0.9	12.3	8.2	0.3	3.7	4.9	7.7	22.1	4.2	9.3
	T. pyri	0.06	0.00	0.06	0.16	0.24	0.12	0.50	0.50	0.64	0.54	0.38	1.16
diflubenzuron and 'Dipel' (12.5+ 50+)	*P. ulmi*	2.0	1.2	0.7	6.3	9.8	0.9	1.6	1.3	6.5	21.7	25.7	14.0
	T. pyri	0.06	0.10	0.14	0.16	0.22	0.14	0.42	0.26	0.86	0.94	1.84	1.90

** X3 concentrate * cyhexatin (13 g/100 1) applied 14.12.77. + g formulated material

(Table 5) and thereby prevented leaf damage on all but the most densely infested trees of both treatments.

T. pyri again survived the diflubenzuron/'Dipel' sprays at similar densities to those in the 'control' treatment but the high levels of European red mite in both treatments indicated that disruption of natural control by diflubenzuron in 1976-77 carried over into the following season.

In the 'Sturmer Pippin' trees *T. pyri* rose to almost 4/leaf in March in both the treated and 'control' trees. European red mite increased briefly to about 45/leaf in February under the diflubenzuron/'Dipel' sprays before *T. pyri* reduced the population. The fruits carried few mite eggs (Table 2). These results for 1977-78 reinforced the evidence of the previous two seasons that diflubenzuron disrupted Euorpean red mite populations but not through toxicity to *T. pyri*.

DISCUSSION

These experiments have confirmed existing evidence of the effectiveness of diflubenzuron in controlling codling moth. Audemard *et al* (1975) showed that this chemical was toxic to codling moth larvae. The present work has shown that it is also ovicidal, either directly or/and mediated through the ovipositing female. The eggs died at all stages and many developed to the 'red-ring' or 'black-head' stage before mortality occurred.

The present work has also shown that diflubenzuron, at rates as low as 0.37 kg/ha, is capable of protecting 'Delicious' fruits from damage by even a dense codling moth population. Sampling showed that eggs were laid at very high density in both the treated and untreated trees. However, at high population density on 'Sturmer Pippin', higher rates of diflubenzuron would be required to protect the fruit.

Although diflubenzuron reduced fruit damage by leafrollers it did not prevent economic damage with respect to the export market. Three species of leafroller were present in the trees and they may differ in their susceptibility to the insecticide. At the rates used the addition of 'Dipel' to diflubenzuron also failed to prevent leafroller damage, particularly to 'Sturmer Pippin' and further work is needed to assess the value of adding 'Dipel' to the diflubenzuron.

Diflubenzuron and diflubenzuron plus 'Dipel' permitted the survival of important natural enemies of European red mite and woolly aphid, notably *T. pyri* and *A. mali* respectively. In preliminary laboratory tests diflubenzuron was not toxic to the active stages or eggs of *T. pyri* (Wearing unpublished). However, the toxicity of diflubenzuron to insect predators of woolly aphid was paralleled by reduced numbers of *S. albisignata*, a predator of European red mite, in the sprayed plots. In a series of three samples in January/February 1976, *S. albisignata* in the control treatment outnumbered those in the diflubenzuron treatment by 24:1. In England this chemical has also been found toxic to predatory bugs (Cranham pers. comm.). *S. bifidus* was encountered too rarely in the above samples to determine the effects of diflubenzuron on this predator species.

Thus, the use of diflubenzuron for control of lepidopterous pests would probably require chemical intervention, albeit minimal, for woolly aphid and mite control. By selectively 'eliminating' insect predators diflubenzuron appears to have provided a demonstration of their importance in control of European red mite in Nelson. This may account for the continued need for occasional applications of selective miticides to assist insecticide-resistant *T. pyri* in the control of European red mite in integrated programmes (Wearing *et al* 1978).

Diflubenzuron with or without 'Dipel' would appear suitable for selective control of codling moth and leafrollers in orchards producing fruit for local consumption. Further experiments on application methods and rates are required to determine whether these materials can meet export standards for leafroller-free fruit. Combining diflubenzuron with insect growth regulators or leafroller virus may provide more effective selective control of codling moth and leafroller than so far achieved.

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