Assessment of indoxacarb for control of Fuller's rose weevil (*Naupactus cervinus*) in New Zealand apple orchards

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Abstract A field spray trial and laboratory bioassay on the residual activity of indoxacarb (Avaunt®) against Fuller's rose weevil (FRW, *Naupactus cervinus*) were carried out. Plots in a block of 'Cox's Orange Pippin' apples with FRW were sprayed with indoxacarb by airblast sprayer in November or mid-December 2014. There were no significant differences between the indoxacarb treatments, but both treatments significantly reduced feeding damage on leaves compared with damage in untreated plots. In a bioassay to assess residual activity of indoxacarb, FRW on treated apple leaves ceased feeding and became moribund or died up to 98 days after the spray application. FRW exposed to treated leaves ceased feeding earlier and died sooner than on untreated leaves. Indoxacarb is registered for use in pipfruit to control leafroller and codling moth, but does not have a label claim in New Zealand for use against FRW. These results indicate the potential effectiveness of indoxacarb against FRW.

Keywords indoxacarb, Fuller's rose weevil, *Naupactus cervinus*, apple.

INTRODUCTION

Naupactus cervinus (Fuller's rose weevil; FRW) is a flightless weevil originally from South America that now has a cosmopolitan distribution (Chadwick 1965; Alonso-Zarazaga & Lyal 1990). The weevil is thought to have arrived in New Zealand via Australia, and was well established by 1940 (May 1993). Adults, which feed mainly on foliage, and larvae which feed on roots, both have a wide host range including many cultivated plants and weeds (Chadwick 1965; Masaki & Kadoi 1997). FRW is found mainly in the North Island and the Nelson region of New Zealand (Ferro 1976; May 1979).

There is only one generation each year in New Zealand (May 1993). Adults emerge from the soil during summer and move into apple trees to feed

by climbing up the trunks. In apple orchards, adults are most numerous in the tree canopy in mid-summer and autumn (P.W. Shaw, Plant & Food Research, unpublished data). At high densities, weevils can lay egg batches on fruit and cause feeding damage to fruit around the stem where they seek refuge during the day. Egg batches can be laid on the cheek of apples where they are very visible and not easily removed by conventional apple washers in packhouses (M. Ewers, Hoddy's Orchard Limited, personal communication). Eggs are also laid in cracks and crevices in both natural and artificial sites, including the spinning heads of micro-sprinklers under trees. Sprinklers blocked by FRW is troublesome for growers as the sprinklers must be cleared at regular intervals throughout the

summer and early autumn to avoid any disruption to irrigation. Although FRW causes little direct damage to apple trees and fruit, it is however a quarantine pest in the export market destinations of China, Thailand, New Caledonia and Mexico.

Thiacloprid (Calypso®) is the only insecticide registered for use on pipfruit to control FRW that is approved for use in the Integrated Fruit Production (IFP) pest control programme. However, thiacloprid can cause mortality of biological control agents in the orchard (Shaw & Wallis 2010; Rogers et al. 2015). There are anecdotal reports from apple growers that indoxacarb can provide some control of FRW (T. Hoddy, Vailima Orchard; M. Thompson, Mahau Orchard; personal communications). Although this insecticide is registered for use in pipfruit to control leafrollers and codling moth, it has a label claim for controlling FRW in Australia but not New Zealand.

Indoxacarb is primarily a stomach poison and does not become effective until it is activated by the enzymes in the gut of an insect. This minimises the risk of harmful effects on beneficial insects and predators, as studies have confirmed (e.g. Dinter & Wiles 2000; Michaud & Grant 2003). This study investigated the potential for indoxacarb to control FRW in apple orchards, which may lead to a label claim for FRW control for indoxacarb in New Zealand.

MATERIALS AND METHODS

Orchard spray trial

A block of mature 'Cox's Orange Pippin' apples with FRW in Motueka was selected for the trial. Spade-width soil samples (17.5x17.5x15 cm deep) were dug throughout the trial block before it was divided into plots to assess the distribution of FRW larvae underneath the apple trees in August and October 2014 (n=58). Indoxacarb (Avaunt® 30WG) was applied by airblast sprayer to the treatment plots at the commercially recommended rate (120 g ai/ha, water rate 667 litres/ha). There was an untreated control (Trt 1) and treatments were applied either on 20 November 2014 (Trt 2) or 12 December

2014 (Trt 3) over the period when indoxacarb can be used for codling moth or leafroller control. There were three plots of 48 trees (6 rows by 8 trees, 600 m²) for each treatment in the block. No other insecticides that affect FRW were applied.

Circular funnel traps were stapled around the trunks of four individual trees in the centre of each plot and monitored weekly from 15 December 2014 to 25 May 2015 to record the number of adult weevils that emerged and climbed the tree trunks to feed in the canopy. The number of leaves with feeding damage, indicated by distinctive notching around the margin of the leaf, was recorded during a three-minute timed search of four trees (excluding the trees with trunk traps) in each treatment plot on 30 January and again on 21 April 2015. We carried out two assessments on 13 and 26 February 2015 during the harvest period when weevil numbers were increasing. Five fruit clusters on eight trees per plot (120 clusters per treatment) were examined on each occasion. The number of (a) adult weevils, (b) FRW-damaged fruit, (c) fruit with FRW frass and (d) brown staining of fruit caused by the frass were recorded.

Laboratory test of the efficacy of field-aged residues on Fuller's rose weevil adults

A bioassay, as described by Rogers et al. (2011), was carried out to assess the efficacy of field-aged residues of indoxacarb against FRW. On 17 February 2015, indoxacarb (Avaunt® 30WG) was applied at an equivalent rate (0.06 g ai/litre, 2000 litres/ha) to that in the spray trial. A small spray unit with a hand gun was used to apply the insecticide to two 'Braeburn' apple trees at the New Zealand Institute for Plant & Food Research Limited Centre at Riwaka. Some trees were left unsprayed to provide leaves with no indoxacarb residues. Treated and untreated leaves were collected at intervals between 0 and 98 days after the indoxacarb treatment, the interval between collection being shorter (3 days) initially and extending out to approximately fortnightly. For each assessment, ten leaves were picked from trees with and without indoxacarb residues and

Table 1 Mean numbers per plot (SE in brackets) of Fuller’s rose weevil trapped (15 Dec. 2014 to 25 May 2015), feeding-damaged ‘Cox’s Orange Pippin’ apple leaves (30 Jan. and 21 Apr. 2015), apples with frass or stain, live weevils and weevil-damaged apples (13 Feb. and 26 Feb. 2015 combined) under the following treatments: (1) untreated control (2) indoxacarb applied on 20 Nov. 2014 (3) indoxacarb applied on 12 Dec. 2015. P values generated by ANOVA analyses are shown for a comparison between the three treatments (overall), treatment 1 compared with the average of treatment 2 and 3 (Trt 1 vs Trt 2 & 3) and between the two indoxacarb treatments (Trt 2 vs 3). Significant differences marked in **bold**.

Assessment	Treatments			P value		
	1	2	3	Overall	Trt 1 vs Trt 2 & 3	Trt 2 vs Trt 3
No. of FRW trapped on tree trunks	228	106	144 (33)	0.177	0.089	0.517
No. of FRW-damaged leaves	32 (2)	8 (1)	8 (0)	0.003	0.001	0.981
No. of apples with FRW frass or stain	27 (4)	11 (2)	13 (1)	0.031	0.013	0.690
No. of live FRW	5 (2)	1 (1)	1 (0)	0.167	0.167	0.865
No. of FRW-damaged apples	3 (1)	2 (2)	2 2(	0.782	0.782	1.000

placed in individual Petri dishes with the stem freshly cut and inserted into small blocks of floral foam previously soaked in water. The floral foam was moistened with water periodically during the assessment period. FRW collected from unsprayed trees at the Motueka spray trial site were placed into Petri dishes (one per dish). Leaves with leaf margins that were eaten by FRW were recorded to indicate feeding activity. Weevils were monitored until those on treated leaves were all dead or moribund. The weevils were considered to be ‘dead’ if no movement was detected when prodded and ‘moribund’ if they were unable to walk in a coordinated manner. Moribund individuals often remained in a state of paralysis for a long period and could manage only to twitch slightly when gently prodded. As moribund weevils were incapable of feeding and unable to recover, FRW scored as moribund or dead were combined for the analyses.

Statistical analyses

For the orchard spray trial, total counts for each plot were subjected to ANOVA, using GenStat (Version 17.VSNi Ltd, Hemel Hempstead, United Kingdom). Two models were fitted: one comparing the three treatments (‘Overall’ in Table 1); the second split into two elements: the

difference between the control and the average of the two indoxacarb treatments (Trt 1 vs Trt 2 & 3 in Table 1), and a contrast comparing the application times of indoxacarb (Trt 2 v. Trt 3 in Table 1). The mean number of FRW larvae in the soil samples was used as a covariate in the analysis.

Logistic regressions were fitted for each assessment time by treatment combination in the laboratory bioassay, and used to estimate LT_{90} (the time at which 90% of the FRW had become moribund or died). LOESS smoothed curves were fitted. These analyses were undertaken using R 3.1.2.

RESULTS

Orchard spray trial

Soil samples for FRW larvae showed that there was no obvious difference in weevil distribution in the block (not shown). This observation was reinforced since including the mean number of larvae found in trial plots as a covariate did not improve the results of the statistical analysis.

There were significant differences between the treatments for some assessments. The number of leaves with feeding damage and the number of apples with frass or staining were significantly higher for the unsprayed control (Trt 1) than for the average of the two indoxacarb treatments

(Trt 2 and Trt 3), but there were no significant differences between the November and December indoxacarb treatments (Table 1). More FRW were recovered in the traps on tree trunks in the control treatment than in the two indoxacarb treatments, but the differences were not significant (Table 1). The main period of weevil emergence occurred during March (not shown) and very few FRW adults and weevil-damaged apples were recorded at harvest in February in all treatments. Consequently, there were no statistically significant differences in these assessments (Table 1).

Laboratory test of the efficacy of field-aged residues on Fuller's rose weevil adults

FRW exposed to treated leaves ceased feeding earlier than those on untreated leaves (Figure 1) and became moribund or died much earlier than those on untreated leaves, up to 98 days after application (Figure 2). Most of the weevils on treated leaves fed only once and only a minor amount of leaf chewing was evident compared with more sustained and extensive feeding by weevils on untreated leaves. The time for weevils on treated leaves to become moribund or die increased with days after application. The estimated time for 90%

Figure 1 Number of leaves with evidence of feeding by *Naupactus cervinus* (Fuller's rose weevil) (n=10 weevils) for each assessment on field-aged leaf residues of indoxacarb (0-98 days after treatment) plotted against the number of days on the 'Braeburn' apple leaf for untreated control (circles) and treated (triangles) leaves.

Figure 2 Number of moribund or dead *Naupactus cervinus* (Fuller's rose weevil) (n=10) for each assessment on field-aged leaf residues of indoxacarb (0-98 days after treatment) plotted against the number of days on the 'Braeburn' apple leaf for untreated control (circles) and treated (triangles) leaves..

of the FRW to become moribund or die (LT_{90}) on 50 and 98-day-old treated leaves was 10 days and 17 days respectively, compared with ca 40 days for weevils on untreated leaves (Figure 3).

DISCUSSION

Field assessments from an orchard spray trial and a bioassay of field-aged residues confirmed that indoxacarb was effective against adult FRW. There were significantly more FRW-damaged leaves in

the untreated control than in the two indoxacarb treatments. The assessment of apples with FRW frass or fruit staining (caused by the frass), was used as an indicator of FRW presence. There were significantly more apples with frass or fruit stain in the control than in the indoxacarb treatments. Very few apples were found with FRW present or with feeding damage to show any treatment differences, probably because 'Cox's Orange Pippin' is an early harvested apple cultivar and the population of

Figure 3 Estimated time (days) for 90% of *Naupactus cervinus* (Fuller's rose weevil) to become moribund or die for untreated control (solid circles, solid line) and treated (triangles, dashed line) 'Braeburn' apple leaves. The lines show the LOESS smooth fits, and the grey bands their point-wise 95% confidence intervals. The first two assessments for the untreated leaves are shown (open circles) but were not included in the LOESS smooth fits because some of the weevils may have inadvertently been collected from an indoxacarb treated plot.

FRW had not peaked in the canopy at harvest time in February when they were examined.

Indoxacarb is primarily a stomach poison and becomes activated in the insect's gut, causing paralysis and rapid inhibition of insect feeding (Dinter & Wiles 2000). Ingestion of the leaves would explain the results in the bioassay that showed adult FRW placed on field-aged residues of indoxacarb on apple leaves became moribund or died much earlier than those on untreated leaves, and ceased feeding on leaves earlier than FRW on untreated leaves. There was high mortality of FRW adults exposed to indoxacarb residues up to thirty five days after application and some mortality up to ninety eight days. Because of its specific mode of action, indoxacarb is considered

to be safe or to cause minimal disruption to many biological control agents, which makes it compatible for use in Integrated Pest Management (IPM) programmes (Dinter & Wiles 2000).

Spray trial assessments of leaf-feeding and incidence of FRW frass and staining on fruit indicated that indoxacarb applied either in mid-November or mid-December provided control of FRW, although there was no significant difference between the two application dates. Application over this period is necessary to avoid possible residue issues at harvest and has the benefit of providing leafroller and codling moth control. However, since our trial was on an early-harvested apple cultivar, and adult FRW were still emerging and climbing into the canopy to feed in February,

the December timing would be more appropriate on cultivars with later harvest windows, being mindful of pre-harvest withholding intervals to avoid possible issues with fruit residues. This later timing and the long period of residual activity of indoxacarb against FRW demonstrated in these trials should help to control FRW in the apple canopy through summer and autumn.

Currently, thiacloprid is the only insecticide registered in the pipfruit sectors Integrated Fruit Production (IFP) programme for control of coleopteran pests. However, it can cause some disruption to biological control agents in orchards. Other pesticides need to be evaluated for control of coleopteran pests in New Zealand pipfruit orchards. In Australia, indoxacarb is registered for use on pipfruit to control a range of weevil pests including Fuller's rose weevil (*Naupactus cervinus*), Apple weevil (*Otiorhynchus cribricollis*) and Garden weevil (*Phlyctinus callosus*), and another coleopteran pest, Monolepta beetle (*Monolepta australis*) on soybeans. Its registration in New Zealand, currently for leafroller and codling moth control in pipfruit, is likely to be retained and extended for control of some other insect pests, including FRW on apples pending more efficacy data to support label claim additions (M. Christie, DuPont Crop Protection NZ, personal communication). Our study has confirmed that indoxacarb has a lengthy period of residual efficacy against FRW. Registration in New Zealand for its use against this pest would provide pipfruit growers with an effective insecticide option that is least disruptive to IPM programmes.

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