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Modelling pesticide residues on greasy wool: surveys of the insect growth regulators triflumuron and diflubenzuron

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Summary. Surveys have examined the relationship between louse and flystrike treatments on farms and the resulting residues of insect growth regulators on greasy wool. These results have been summarised using a model of the on-farm survey data. The model estimated the amount of chemical taken up by the wool at application. This was based on experimental breakdown rates of these insecticides on wool determined in controlled trials.

The data indicated that the backliner, triflumuron, when used off-shears within 24 h of shearing, was normally applied at slightly higher than the recommended rate on-farm and left an average residue of 30 mg/kg greasy wool at the following shearing 12 months later. Diflubenzuron, applied by dipping or jetting, was usually applied at lower than the recommended rates, and left an average residue of 40 mg/kg on the wool at shearing 12 months later. When treatment was applied to very short wool (<3 weeks after shearing) the residue was only about 20 mg/kg, but when applied at later times after shearing the residue at the following shearing was not closely related to the time of treatment.

The model can be used to estimate the expected residue level and likely range of results from most standard insect growth regulator treatments. This will improve advice to producers so most can meet specified industry standards.

Introduction

Several surveys of insecticide residues in wool (Pattinson 1995; Plant 1995; Horton *et al*. 1997; Ward and Armstrong 1998*b*, 1998*c*) have shown that residues in the shorn wool are generally low, but substantial concentrations of insecticide may remain on wool following treatments such as long-wool dipping, jetting sheep close to the next shearing and repeated applications in long wool. These results have been supported by experimental studies (Campbell *et al*. 1995, 1998). In some cases this may result in concentrations of insecticide in wool scour effluent that may exceed environmental standards for effluent disposal, with potential danger for Australian wool markets (Russell 1994; Pattinson 1995).

Ward and Armstrong (1998*a*) reported that although the use of organophosphates (OP) and synthetic pyrethroids (SP) has declined, the use of so-called insect growth regulators (IGRs) such as diflubenzuron and triflumuron has increased.

Data on IGR residues on wool following known treatments were analysed here using breakdown rates derived by Campbell *et al*. (1998, 1999). This allowed estimation of the amount of chemical that had been applied in each case, so that a model could be developed considering common methods and times of treatment. A similar model was developed for organophosphates and synthetic pyrethroids (Plant *et al*. 1999).

Materials and methods

Surveys

Surveys in Tasmania and Western Australia were carried out by selecting producers known to have used a specific IGR. Suitable lines of their wool were selected as representative of the treatment

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applied. Subsamples from the core samples taken by the Australian Wool Testing Authority (AWTA) were forwarded to CSIRO Wool Technology, Geelong, or the State Chemistry Laboratory, Werribee, for testing for pesticide residues. The Queensland survey has been described by Ward and Armstrong (1998*b*). Random samples of sale lot fleece wool were sent to the Queensland Department of Primary Industry Chemical Residues Laboratory to be tested for all ectoparasiticides. Where possible, the owners of the fleece lines were identified and requested to supply information on the treatments applied to the sheep that provided the sampled wool. Samples were included in this survey if they were positive for diflubenzuron or triflumuron and had satisfactory producer records of treatments applied. The number of lots in each category are shown in Table 1.

Variables considered in the model

Effect of application method on the amount of chemical retained in the fleece. For the analysis of diflubenzuron results, separate variables were used for the mass of chemical retained in the fleece by: (i) hand jetting or jetting race, and (ii) plunge or shower dipping. In the case of triflumuron, application is by off-shears backliner. An additional variable allowed for a different application rate of diflubenzuron in Tasmania compared with the other states, since preliminary analysis and survey information provided by producers suggested that lower than recommended application rates were common in Tasmania.

Effect of length of wool on the amount of chemical retained in the fleece. Triflumuron is applied off-shears by measured dose, but diflubenzuron can be applied at different times by a range of methods. The model described previously for organophosphate pesticides was used to relate the amount applied to the length of wool (Plant *et al*. 1999).

The estimate of the amount applied is

$$A0 \times W1 \times W2 \text{ (mg/sheep)}$$

where the variable $A0$ controlled the estimate of the maximum amount that could be applied by any given treatment method, and

$$W1 = FW/(W + FW)$$

where FW is the proportion of 12-month fleece weight at the time of treatment, and W is the wool application variable, in the range 0–1. When W is 0, $W1$ is not affected by length of wool at the time of treatment. When W is low, the amount of chemical taken up by the wool is high even in relatively short wool. When W equals 1, the chemical taken up into the wool is directly proportional to wool length. Therefore W can be adjusted to ensure that $W1$ allows for any reasonable effect of wool length on the amount of chemical taken up by longer wool.

$W2$ represents the amount of chemical applied by the producer as a proportion of the maximum applied. It is in the range 0–1, changing at a constant rate from one shearing to the next. $W2$ is not intended to represent the recommended rate, it is simply a variable to account for the fact that wool producers may increase or decrease their application in a consistent manner as the length of the wool increases or as the next shearing approaches.

Pesticide residue on wool at any day after treatment. The rate of breakdown has been shown to change over time, from a faster initial rate to a slower steady-state rate. For this reason each day of pesticide breakdown was considered consecutively using the model developed previously (Campbell *et al*. 1998) but including breakdown rates determined from short wool studies (Campbell *et al*. 1999). The latter study found differences in breakdown rate between different regions of Australia. In the analyses presented here the breakdown rate in Tasmania was taken to be 75% of the rate in Victoria, and the breakdown rates in Western Australia and Queensland were double the Victorian rate. R. T. F. Armstrong (unpublished data) found regional differences in Queensland, with higher rates of pesticide breakdown in the hotter drier regions than in the cooler elevated areas. Similar variation probably occurs in other states but sufficient data are not available to include these regional variations in the model.

Fitting the model to the data

For each pesticide the model could have several variables: (i) amount applied depends on the method of application (jetting *v*. dipping); (ii) amount applied may vary depending on the length of wool at application; and (iii) amount applied may differ in different states.

These variables are interrelated and cannot be optimised independently of each other by the model. A genetic algorithm (Horton 1996; Campbell *et al*. 1998; Plant *et al*. 1999) was used to allow all the model's variables to change over a wide range simultaneously until a set was found that best fitted the data (using least squares on a logarithmic scale). The resulting model should be very close to the best possible fit to the data, using the defined assumptions.

Table 1. Best fit model for application of insect growth regulators on-farm

The amount of pesticide taken up by the fleece (mg/sheep) is $A0 \times W1 \times W2$ where $W1 = FW/(W + FW)$ and FW is the proportion of a 12-month fleece at the time of treatment; $W2$ changes linearly from the value at day 0 to the value at day 365; W is a variable used to allow for changes in the amount of chemical taken up by the wool (or changes in the amount of runoff) due to the length of wool on the sheep at the time of treatment

The model indicates that Tasmanian producers apply only 54% of the above amounts of diflubenzuron (compared with Western Australian and Queensland producers)

Values for W and $W2$ are not relevant for treatment applied only off-shears

Chemical	Method of treatment	No. of lots tested	$A0$	W	$W2$ at day 0	$W2$ at day 365	Standard deviation (as a factor)	Estimated amount retained in fleece wool (mg/sheep) Off-shears	6 weeks	6 months
Triflumuron	Backliner	58	810	—	—	—	1.8	810		
Diflubenzuron	Dipping	14	373	0.007	1.00	0.24	1.8		359	
Diflubenzuron	Jetting	17	357	0.007	1.00	0.24	2.2			240

Results

The results for the model's estimates are summarised in Table 1. The average concentration of triflumuron in wool shorn 12 months after off-shears treatment was 30 mg/kg. The distribution of these triflumuron residues is shown in Figure 1. For diflubenzuron, where sheep were shorn with 12 months wool the average residue following dipping or jetting was 40 mg/kg.

Degree of fit to the data

The standard deviation for pesticide residue concentration on greasy wool on the $\log_{10}$ scale was 0.257 for triflumuron and 0.327 for diflubenzuron. Therefore any estimate of expected residue from a known treatment has a possible error factor of 1.8 for triflumuron and 2.2 for diflubenzuron (Table 1).

Figure 2 shows the model for diflubenzuron and the actual data used to obtain the curve.

Amount of chemical retained by the fleece

The amount of diflubenzuron retained by the fleece wool increased as the length of wool increased up to 4 weeks after shearing but less chemical was retained at later times (Fig. 3). Diflubenzuron is not registered for use within 6 months of the next shearing so insufficient data were available to determine the amount retained in more than 6 months wool. The amount of triflumuron applied by off-shears treatment (810 mg/sheep) is also shown in Figure 3.

A sheep dipped or jetted with 2.5 L of diflubenzuron formulation at the recommended rate would receive 938 mg diflubenzuron (treatment for lice) or 1250 mg (to prevent flystrike). In actual practice, much less than the recommended rate of diflubenzuron appeared to be applied by dipping and jetting. Producers in Tasmania reported that they applied only 0.5–1.5 L of diflubenzuron mixture per sheep and some of this was applied to the breech, not to fleece wool. This is well below the manufacturer's suggested application of 2.5 L for jetting.

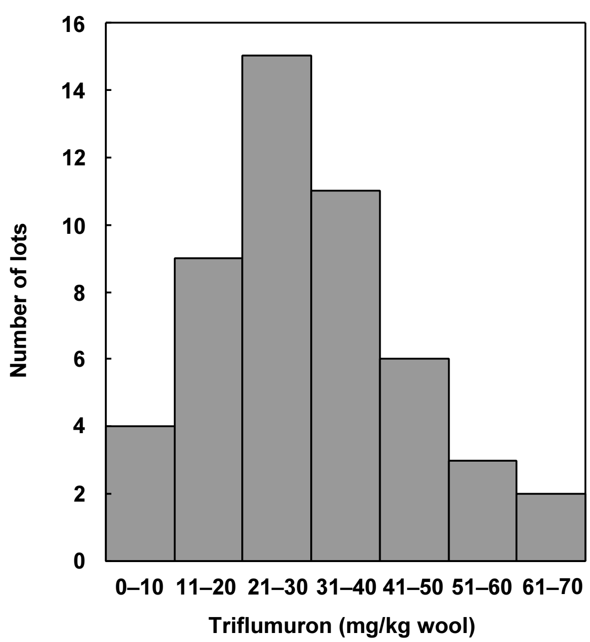

Figure 1. Distribution of triflumuron residues on wool shorn 12 months after off-shears treatment.

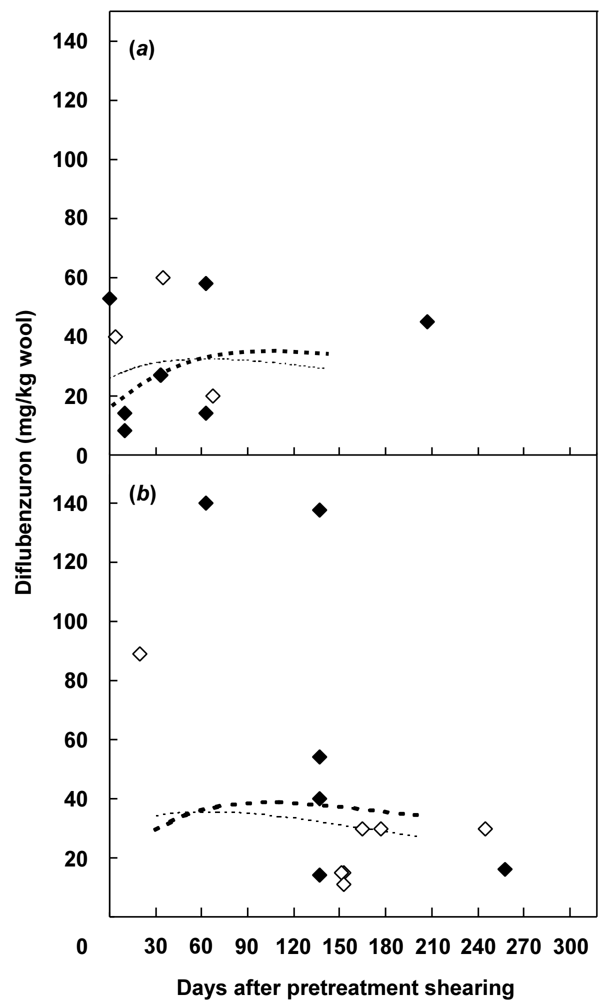

Figure 2. Pesticide on sheep at shearing after diflubenzuron application. Fitted curves: thick line, Western Australia and Queensland; thin line, Tasmania. Actual data points: solid points, Western Australia and Queensland; open points, Tasmania. (*a*) Plunge or shower dipping; (*b*) hand jetting or jetting race.

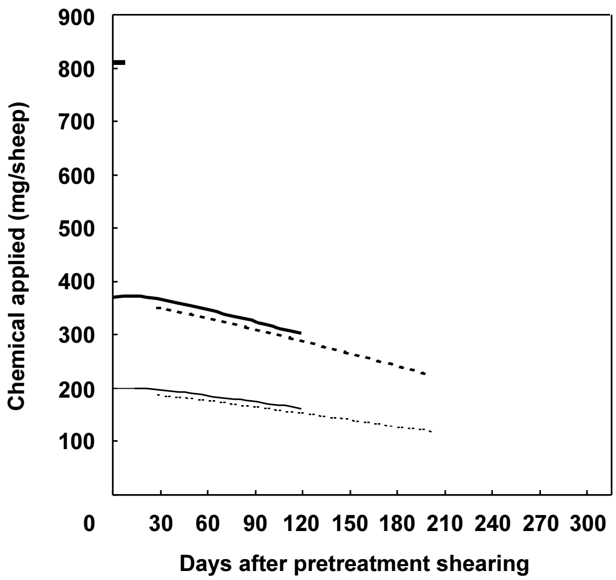

Figure 3. Estimated amount of triflumuron and diflubenzuron applied to sheep by wool producers. Thick lines, Western Australia and Queensland; thin lines, Tasmania; solid lines, plunge or shower dipping; dotted lines, hand jetting or jetting race; short thick line at 810 mg/sheep, triflumuron off-shears.

Discussion

Use of the appropriate breakdown rates to interpret the survey data provided an estimate of the amount of chemical actually applied by producers. Results previously obtained for organophosphates showed substantial variation in the amount of chemical applied and the wool residue resulting from common treatments, but the results reported here are less variable.

The recommended rate of application for triflumuron is 500 mg for a 50 kg sheep. The data suggest that the actual amount applied is about 800 mg/sheep. This estimate depends on the assumed breakdown rate so it may be too high if the actual breakdown rate is slower than the rate used here. However, producers in this survey often stated that an extra dose may be applied if the sheep move during application (e.g. if the chemical is not correctly applied to the backline), or the application does not cover the full length of the sheep from poll to tail as required. One of the authors noted that on a number of occasions under field conditions farm workers using the recommended volume ran out of chemical before reaching the end of the sheep, so they gave an extra dose to overlap the first application. As a result, a large proportion of the flock may receive an extra 20–30% more than the normal dose. The estimated amount applied has a standard error of about 20% so the results reported here are consistent with a moderate level of overdosing to ensure complete coverage of the treated animals.

The estimated amount of diflubenzuron retained by the fleece is lower than expected. The manufacturer's recommended treatment rates would apply 938–1250 mg per sheep depending on the method of application and pest being treated. The product does not strip, so half of this might be lost in runoff in the case of jetting. This leaves 469–625 mg applied per sheep compared with the estimated 240–359 mg in this survey. However, this is an expensive product and wool producers may be inclined to avoid high application rates, so under-dosing may be more common than over-dosing, in contrast to triflumuron where the reverse may apply due to the method of application.

In other studies the rate of breakdown of diflubenzuron in Tasmania has been lower than in the other states studied here (Campbell *et al*. 1999). The actual wool residue concentrations were similar in all states, indicating that Tasmanian wool producers apply less diflubenzuron. This conclusion is supported by their descriptions of the method used. They generally applied very low volumes of the mixture when jetting sheep (often <1 L) and sometimes applied the chemical mainly to the breech, with only a small proportion on the fleece wool.

The amount applied in experimental studies (Campbell *et al.* 1999) was similar to the recommended rate, but the residues obtained in that study were much higher than occurred in these surveys with common farm practice.

The results of these surveys are similar to those of the national survey conducted by the Woolmark Company, where the average concentration for those wool lots containing >1 mg/kg of these chemicals was 33 mg/kg for diflubenzuron and 31 mg/kg for triflumuron (Savage 1998).

There was more variation in the diflubenzuron results, as would be expected, since triflumuron is always applied by a measured dose using the manufacturer's applicator without additional dilution of the product, although errors in setting and operating the applicator may occur. The mean diflubenzuron residue was 40 mg/kg. This was similar for all application methods and wool lengths, except for very short wool applications, which left lower average residue concentrations. Diflubenzuron was used in only a small number of samples and the model should not be considered to be accurate for this chemical without further validation.

For all methods and chemicals there was a high level of variation, after allowing for the method of application, length of wool, and time from treatment to shearing. However, the variation was much less than in previous surveys of OP and SP use (Plant *et al*. 1999), where the model's estimate could vary by a factor of 3.8 (organophosphates) or 3.4 (synthetic pyrethroids) compared with 1.8–2.2 as in this survey. The Tasmanian and Western Australian producers had been requested in advance to record the dates of treatment, and the Queensland producers were more likely to have kept accurate records because these treatments are relatively new and more expensive than OPs or SPs.

The narrower range of results could also be a result of the slower rate of breakdown of these chemicals. Organophosphates have a rapid rate of breakdown (Campbell *et al*. 1998), so there are many half-lives between treatment and shearing. This magnifies any error in estimating the actual breakdown rate under the actual conditions occurring on the farm. This would lead to a wider range of error for short wool OP treatments than for similar IGR treatments where the results are much less sensitive to variations in the time between treatment and the next shearing and to factors that change the breakdown rate.

The model developed here can estimate the residue expected from a wide range of pesticide treatments. This will assist in providing advice to producers regarding the residue resulting from standard treatments. Conversely if the residue, method and time of treatment are known, the model can estimate the amount of chemical that must have been applied to obtain that result. This has provided an estimate of the common rates of application in actual on-farm use and will assist in providing advice about routine farm treatments. When maximum pesticide targets are set for specific markets, the model can be used to suggest appropriate withholding periods to ensure meeting those market requirements.

A review of sheep ectoparasiticides by the National Registration Authority (Savage 1998) has suggested that Australian wool processors could meet environmental standards provided that wool sale lots did not exceed 150 mg triflumuron/kg or 65 mg diflubenzuron/kg. The average residue level in this survey was below these limits, although some wool lots did exceed 65 mg diflubenzuron/kg.

The requirements for European markets are expected to be lower, with a proposed maximum acceptable wool residue level of 37 mg triflumuron/kg and 9 mg diflubenzuron/kg. Normal use of triflumuron with shearing 12 months later would meet these requirements, but application of diflubenzuron, except possibly in very short wool, would exceed 9 mg/kg.

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