Modelling Canopy Interactions for Drift Mitigation

Peter Walklate
Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, UK

Abstract

The information generated by this research is aimed at the development of practical drift mitigation strategies for broadcast air-assisted spraying of fruit crops in the UK. Previous field studies have shown that off-target drift contamination decreases significantly between the beginning of flowering (i.e. worst-case drift condition) and full-leaf development. This paper describes a modelling approach that links the changes in off-target drift contamination to the structural changes of the target orchard. The model utilises information about the optical transmission range probability distribution of the target orchard. This information is derived from a tractor mounted LIDAR system that provides an idealised optical analogue of spray droplet transmission in the target trees closest to the sprayer. Results are presented to compare the use of different dose adjustment methods for reducing the risk of drift contamination during the application of plant protection products.

Introduction

The application of Plant Protection Products (PPP's) to "Fruit crops" with air-assisted sprayers produces much higher risk of drift contamination than other common types of ground spraying activity, including those used for treating: "Field crops" "Grapevines" and "Hops" (Ganzelmeier *et al*., 1995). Therefore, the recommended no-spray zones for suitable environmental protection from key PPP's may be too long for practical use by many European fruit growers. Alternative drift mitigation strategies are needed to provide a practical means of using these products with existing spraying equipment and meeting the new challenges set by implementation of the Plant Protection Product Registration Directive 91/414/EEC.

In this paper a modelling approach is developed to examine the possibilities for drift mitigation, based on the use of practical methods of dose adjustment that may be used by fruit growers. The approach builds on the principles of Pesticide Adjustment to the Crop Environment (PACE) that have been established to improve the control of pesticide application by achieving uniform deposition across a wide range of different crop structures (Walklate *et al*., 1996; Cant *et al*., 2002; Walklate *et al*., 2002; Walklate *et al*., 2003).

Modelling Concepts

Spray drift

The objective is to establish a simple model of spray drift to facilitate the comparison of different dose adjustment methods that may also be used for drift mitigation purposes. To achieve this, the airborne drift flux variation with orchard growth stage is first represented by the following power-law model

$$D_a = a_i U^m T^n \qquad (1)$$

where the drift flux is expressed as a fraction of the applied spray volume application rate, U is the ratio of the actual to maximum wind speed, T is the optical transmission which is also a function of growth stage and a_i, m & n are all empirical coefficients that are independent of growth stage. This model may be easily used as the basis for regression analysis of typical drift measurements (Cross *et al*.,2001a; Cross *et al*., 2001b; Richardson *et al*., 2002; Cross *et al*., 2003; Richardson *et al*., 2004; Walklate *et al*., 2004;) and/or for source modification of existing models that predict only the spatial distribution of drift (Walklate 1992; Xu *et al*., 1997).

Dose adjustment

Various methods of dose adjustment have been developed for air-assisted orchard spraying and these have been summarised by Walklate *et al*.(2002). To facilitate comparison of these methods, suitable elements of the generic framework for dose expression are used here (Walklate *et al*., 2003). Part of this framework is the following model for spray volume deposition and, when expressed as a fraction of the applied spray volume application rate, is

$$D_t = \frac{W}{L} \qquad (2)$$

where L is a length-scale function (i.e. proportional to the target crop area per unit row length and inversely proportional to the spray volume fraction on target) and W is the spatial interval between spray applications

To obtain constant tree average deposit of PPP's (i.e. volume or mass of product per unit area of target crop) across a wide range of different structures, Equation (2) is used to determine the ratio of applied dose to label dose, as follows:

$$R = \left(\frac{W^*}{W}\right)\left(\frac{L}{L^*}\right) \qquad (3)$$

where W^* and L^* refer to the worst-case values that are used to establish the maximum label dose based on suitable efficacy trials. For practical methods of dose adjustment the length-scale function L is approximated by the simple scaling rules, summarised in the table 1.

Table 1 Summary of length-scale approximation functions for different practical methods of dose adjustment

Name of dose adjustment method	Key crop scaling parameter	Length-scale approximation function*
Label	Spatial interval between spray applications	$L \propto W$
Fruit wall area (FWA)	Fruit wall area divided by the row length (i.e. Average tree height)	$L \propto H$
Tree row volume (TRV)	Tree row volume divided by row length (i.e. Average tree cross-sectional area)	$L \propto CSA$
Tree area density (TAD)	Target area of tree row divided by row volume (i.e. Tree area density)	$L \propto TAD$
Full optimised (FO)	Target crop area per unit row length for constant volume fraction on target	$L \propto TAD \times CSA$

* These approximations are all limited to the deposition conditions below spray saturation.

Measurements

General remarks

Measurements of airborne drift, wind speed and crop structure are used to illustrate the modelling concepts outlined in the previous section. These measurements are all extracted from a previous field study (Walklate, 2004), using the data for the semi-dwarf apple orchard during the period 5th October 2000 to the 21st March 2002.

Spray drift

The experiments results, described as airborne drift, have been obtained by averaging the spray volume flux collected onto 6 vertical lines of 1.98mm plastic tubing. These line collectors sample the lower 10 m of the atmospheric boundary-layer at 4.5 m downwind from the end row of the target orchard. The measurements were made during spray application at a constant spray volume rate (*c.* 235 litre ha^{-1}), using a standard axial-fan type air-assisted sprayer (i.e. Hardi TC 1082, operating at the following conditions: airflow rate (*c.* 11.3 $m^3 s^{-1}$), spray flow rate (*c.* 0.19 litre s^{-1}), forward speed (*c.* 1.6 $m s^{-1}$) and "very fine" BCPC spray quality at 0.3 m from the hollow-cone nozzles). Four different areas of the target crop were treated using different spray tracers (i.e. EDTA chelates of different metal). A summary of the different spray treatments is given in Table 2.

Table 2. Description of the different treated area of the target crop during the spray drift measurements

Treatment	Target tree row	Location of sprayer Avenue number[#]
1	1^1	0
2	$1^1, 2^2, 3^1$	1, 2
3	$3^1, 4^2, 5^1$	3, 4
4	$5^1, 6^2, 7^1$	5, 6

[1] Target row was exposed to spray from the nearest outlet on one side of the sprayer.

[2] Target row was exposed to output from both sides of the sprayer.

[#] During each treatment the sprayer was driven in both directions along the avenue(s) of the orchard to randomize the interactions between wind direction and direction of sprayer movement.

Wind speed

Average wind speeds were estimated for the period during each spray application. These were derived from the standard time sequence measurements given by a three component ultrasonic anemometer, mounted at 7m above ground level.

Crop structure

The measurements of crop structure were carried out in a mature apple orchard at Rocks Farm, East Malling, Kent. The orchard was made up of different varieties of dessert apple (i.e. Cox, Spartan and Discovery) all on MM106 rootstock. These were planted at constant intervals (*c.* 3.5m) along the row length (*c.* 66.5 m) and a constant row interval (*c.* 5.0 m). During the measurement period the trees were heavily pruned during the winter dormancy growth-stage of 2000/2001 and 2001/2002.

Detailed recordings of the light transmission range probability distribution were made using a tractor mounted LIDAR system (Schwartz Electro-Optics Inc. "Treesence") and this was set-up to give optical trajectories similar to the spray droplet trajectories through the target trees closest to the sprayer. Walklate *et al* (2002) gives further details of this system, the operational practices and the methods for calculating the crop structural parameters.

Results

The measurements of airborne drift and optical transmission are shown in Figure 1. The wind speeds for the these drift measurements (i.e. ranging from 0.68 to 5.39 m s^{-1}) represent typical conditions for which orchard spraying is approved in the UK (DEFRA, 2004).

Regression analysis

The correlation between drift data and the model estimates, based on the natural log transform of Equation (1), is shown in Figure 2. The data combines the results from 7 experiments, each with 4 spray treatments and 2 estimates of optical transmission (i.e. a total of 56 observations). Regression analysis (Microsoft Excel 2002) shows that the correlation is good (i.e. an adjusted $r^2 = 0.92$ and a standard error = 0.25). The ANOVA output indicates a high significance ($p <$ 0.001) for the estimates of the coefficients in Equation (1) and these are summarised in Table 3.

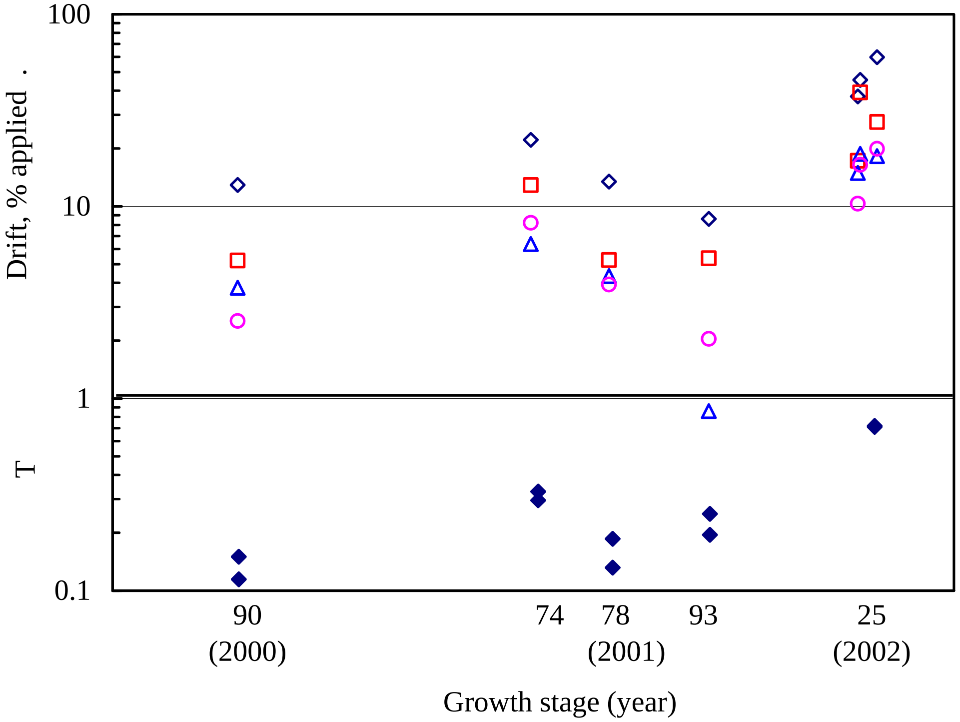

Figure 1. Time sequence measurements of airborne spray drift from different treated areas of an orchard (open symbols as in Figure 2) and optical transmission (solid symbols).

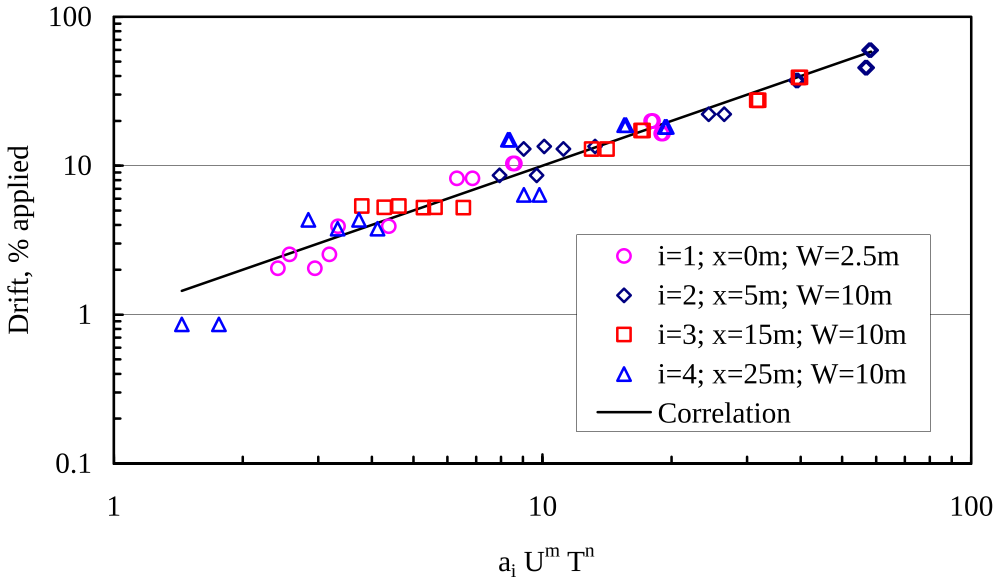

Figure 2. Correlation between measurements of airborne spray drift and a ground source adjustment model of the interaction between crop structure and wind speed given by Equation (1).

Table 3. Drift model coefficients given by multiple regression analysis of data for the natural log transform of Equation (1).

Name of coefficient	Mean	Lower 95% confidence limit	Upper 95% confidence limit
$\ln a_1$	3.25	3.07	3.43
$\ln a_2$	4.45	4.27	4.63
$\ln a_3$	3.95	3.76	4.13
$\ln a_4$	3.39	3.20	3.58
n	0.79	0.69	0.90
m	0.84	0.68	1.00

Prediction of dose adjustment and pesticide drift

Measurements of crop parameters (i.e. W, H, CSA, TAD & T) are used to calculate the applied dose adjustment and spray drift distributions as a function of growth stage (EPPO, 1989). Equation (3) is used to predict the applied dose characteristics (Figure 3) for the different adjustment methods represented by the different length-scale function approximations (Table 1). The pesticide drift characteristics (Figure 4) are obtained by combining the dose adjustment characteristics with the prediction of worst-case values of spray drift at $x =$ 4.5 m (i.e. Equation (1) with $U = 1$ to represent the maximum allowable wind speed of 5.3 m s^{-1} for orchard spraying).

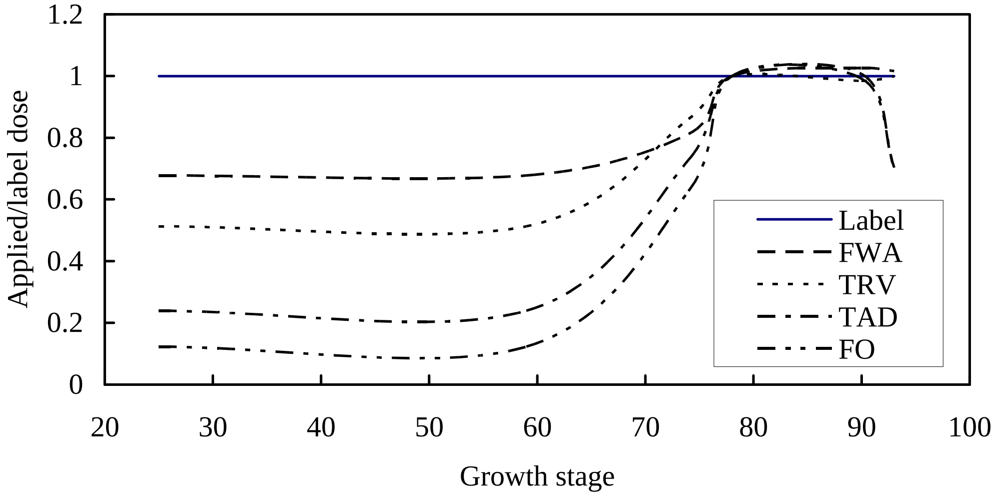

Figure 3. Predicted ratio applied/label dose as a function of growth stage for different methods of dose adjustment listed in Table 1.

Conclusions

A modelling approach has been developed for assessing different drift mitigation strategies based on the methods of dose adjustment that may be used by different fruit grower with air-assisted orchard sprayers. The model utilises LIDAR measurements of optical transmission to predict the characteristics of airborne drift of PPP's leaving the target orchard at different growth stages and the modified drift characteristic for different methods of dose adjustment. Good agreement is demonstrated between the measurements and predictions of drift from a semi-dwarf apple orchard at full-dose application rates. Further validation is required for the predicted drift characteristics when different methods of dose adjustment are used in practice.

The fully optimised method of dose adjustment (FO), involving spray plume adjustments to match average tree size and suitable dose adjustments, offers the greatest potential for drift reduction (*c*. 87%) before growth-stage 60 (i.e. beginning of flowering). The tree area density method of dose adjustment (TAD) is predicted to have a slightly lower potential for drift reduction (*c*. 76%), but avoids the necessity of adjusting the spray plume to match the size of the crop across the full growing season. Other methods of dose adjustment, based of tree row volume (TRV) and fruit wall area (FWA) scaling principles, are predicted to give drift reductions of 49% and 32%, respectively.

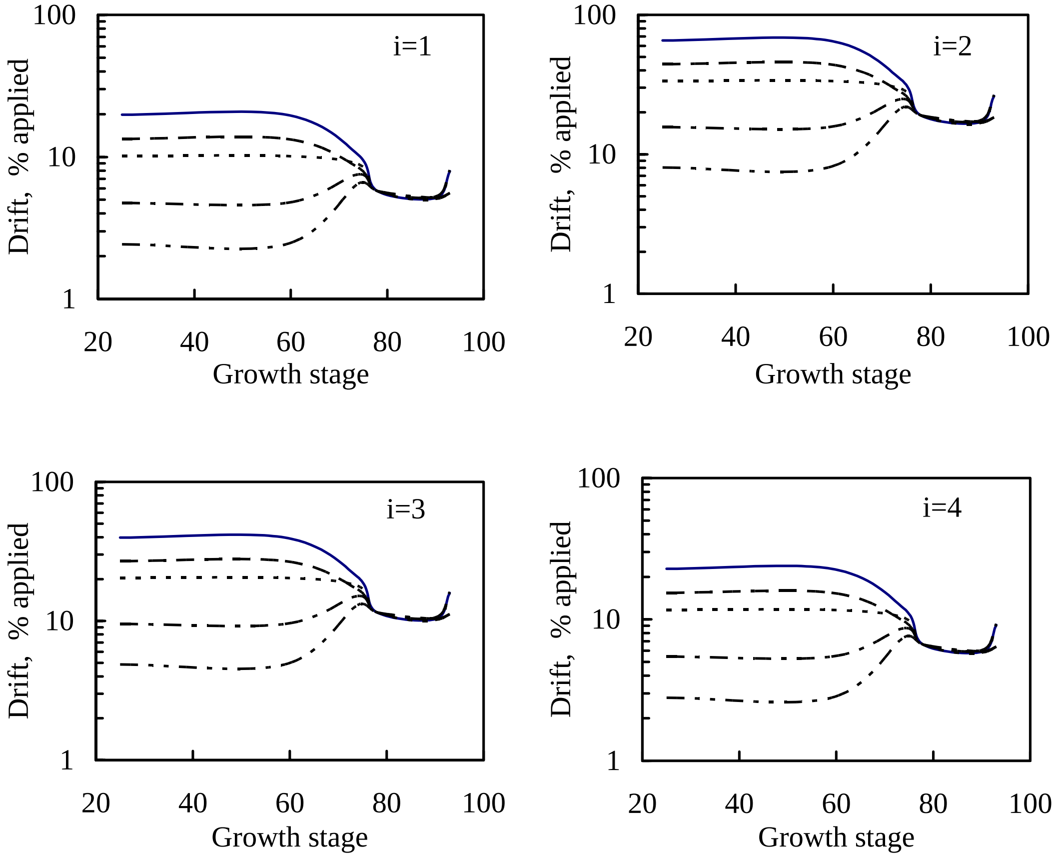

Figure 4. Estimates of airborne drift as a function of growth stage for: a worst-case wind speed of 5.3 m s^{-1}, different treated areas of the target crop (i=1, 2, 3 & 4 listed in Table 2) and different dose adjustment methods (listed in Table 1 & legend key as Figure 3).

Acknowledgement

This research has been funded by the Pesticide Safety Directorate of the Department of the Environment, Food and Rural Affairs in the UK. Thanks are due to: G.M. Richardson and D.E. Baker at Silsoe Research Institute and J.V. Cross and R.A. Murray at East Malling Research for providing inputs to this research.

References

Cant, R., Castro, I. and Walklate, P.J., 2002. Plane jets impinging on porous walls. Experiments in Fluids. 32: 16-26.

Cross, J.V., Walklate, P.J., Murray, R.A. and Richardson, G.M., 2001 (a). Spray deposit and losses in different size apple trees from an axial fan orchard sprayer: 1. Effects of spray liquid flow rate. Crop Protection. 20: 13-30.

Cross, J.V., Walklate, P.J., Murray, R.A. and Richardson, G.M., 2001 (b). Spray deposit and losses in different size apple trees from an axial fan orchard sprayer: 2. Effects of spray quality. Crop Protection. 20: 333-343.

Cross, J.V., Walklate, P.J., Murray, R.A. and Richardson, G.M., 2003. Spray deposit and losses in different size apple trees from an axial fan orchard sprayer: 3. Effects of air volumetric flow rate. Crop Protection. 22: 381-394.

DEFRA, 2004. Draft Code of Practice for the Safe Use of Plant Protection Products, DEFRA London.

EPPO. 1989. Crop growth stage keys – Apple and Pear. Bulletin OEPP/EPPO Bulletin 19: 373-384.

Ganzelmeier, H., Rautmann, D., Spangenberg, R., Streloke, M., Herrmann, M., Wenzelburger, H-J. and Walter, H-F., 1995. Studies on the spray drift of plant protection products. Blackwell Wissenschafts-Verlag GmgH, Berlin.

Richardson, G.M., Walklate, P.J. and Baker, D.E., 2002. Drift reduction characteristics of windbreaks. Aspects of Applied Biology, Pesticide application. 66: 201-208.

Richardson, G.M., Walklate, P.J. and , Baker, D.E., 2004. Spray drift from apple orchards with deciduous windbreaks. Aspects of Applied Biology, Pesticide application. 71: 149-156.

Walklate, P.J., 1992. A simulation study of pesticide drift from an air-assisted orchard sprayer. Journal of Agricultural Engineering Research. 51: 263-283.

Walklate, P.J., 2004. The characterisation of windbreaks for the reduction of drift during orchard and hop spraying. DEFRA report CSG 15 PA1723.

Walklate, P.J., Cross, J. V., Richardson, G M., Murray, R. A. and Baker, D. E., 2002. Comparison of different spray volume deposition models using LIDAR measurements of apple orchards. Biosystems Engineering. 82 (3): 253-267.

Walklate, P.J., Cross, J.V., Richardson, G.M., Baker, D.E. and Murray, R.A., 2003. A generic method of pesticide dose expression: Application to broadcast spraying of apple trees. Annals of Applied Biology. 143: 11-23.

Walklate, P.J., Weiner, K-L. and Parkin, C.S., 1996. Analysis of and experimental measurements made on a moving air-assisted sprayer with two-dimensional air-jets penetrating a uniform crop canopy. Journal of Agricultural Engineering Research. 63: 365-378.

Xu, Z.H., Walklate, P.J. Rigby., S.G. and Richardson G.M., 1997. Stochastic modelling of turbulent spray dispersion in the near-field of orchard sprayers. Proceedings of the 2nd European & African Conference on wind Engineering. Genova, Italy, June 22-26: 413-420.