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Optimising the adjustment of label-recommended dose rate for orchard spraying

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Abstract

Concern for human safety and environmental contamination due to the inefficient use of plant protection products for orchard spraying has resulted in a range of practical models aimed at minimising the orchard-to-orchard variation of deposit through suitable adjustment of the label-recommended dose rate (LRDR) to different crop structure parameters. This study establishes a methodology for optimising model selection by using an appropriate database of crop structure measurements. LIDAR recordings of different orchards at different farms and growth stages have been used to construct an exemplar database of UK pome fruit structures. These recordings were processed initially to reduce each database entry to a set of four parameters describing the tree-row structure, namely: spacing, height, width and area-density. An exact model of LRDR adjustment, assuming minimum spray volume loss and based on all four tree-row structure parameters, was used as a comparator to evaluate the relative performance of different approximation models (i.e. typical regression models based on a reduced set of tree-row parameters). Various approximation models that included the scaling effects of tree-row area-density gave significant agreement with the population of LRDR adjustments predicted by the exact model. The following models gave the best agreement in their class for the percentage of adjustments correctly predicted to within an error tolerance $\pm 1/8$th LRDR (i.e. 80% for the tree-row area-density model and 93% for the combined adjustment model based on tree-row height and area-density). Other approximation models of practical interest gave less significant agreement with the exact model (i.e. 66% for the tree-row-volume model, 55% for the fruit-wall-area model, 50% for the constant adjustment model, 5% for no adjustment). Unfortunately, the practice of LRDR adjustment is currently undermined by many plant protection products that do not give the appropriate reference conditions necessary to define the worst-case crop structure for which acceptable biological performance may be achieved at the full LRDR. Only products aimed at uses in conjunction with integrated pest management schemes give this type of information and typically for use with specific models of LRDR adjustment that ignore the important scaling effects of area-density.

Keywords: Plant protection products; Pome fruit; Spraying; LIDAR; Tree-row structure; Measurement; Modelling

1. Introduction

The dose rate (i.e. the amount of product applied per unit ground area occupied by the crop) is the most commonly used form of dose expression on the labels of modern plant protection products. It is ideally suited to boom spraying applications where a near-planar target crop is located below the spray source. By contrast with this, orchards are typically sprayed from within the canopy using air-assistance so that the deposition of product, applied at the label-recommended dose rate (LRDR), varies with the tree-row volume (TRV) and area-density (Sutton and Unrath, 1984). To mitigate the liability risk associated with the use of orchard spraying products, the manufacturers tend to increase the margin-for-error on the LRDR (Russell, 2004) in preference to using an improved method of dose expression that accounts for the variability of deposit (Furness et al., 1998).

Fig. 1a shows the dose-response characteristics of a typical plant protection product for orchard spraying applications, where the margin-for-error allows for the combined uncertainties of spray deposition, pest or disease pressure and atmospheric conditions. For these products

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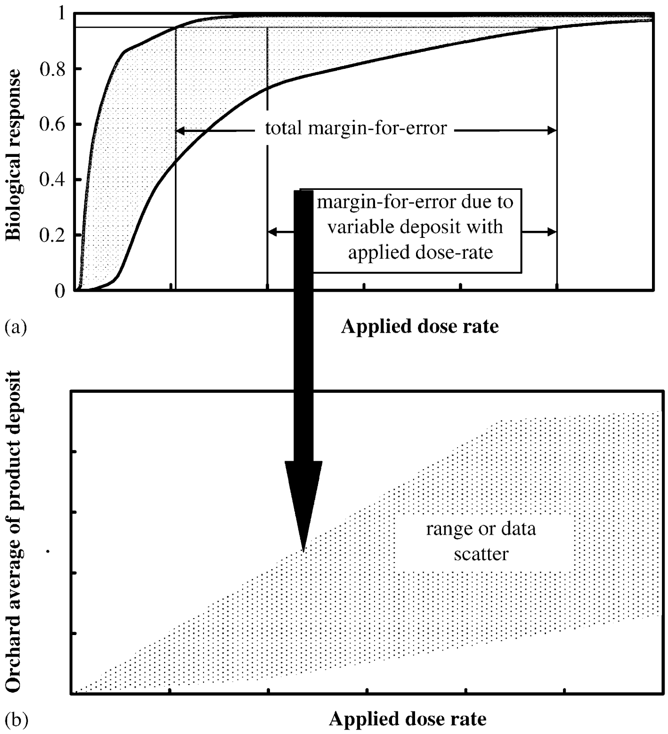

Fig. 1. The relationship between: margin-for-error on the label-recommended dose rate and orchard-to-orchard variability of deposit. (a) Biological response vs. applied dose rate. (b) Average of product deposit for any given orchard vs. applied dose rate showing typical scatter of data.

the variability of tree-row structure contributes to the scatter of deposit due, in part, to the failure of LRDR as a suitable method of dose expression (Fig. 1b). However, with a priori knowledge of key tree-row structure parameters, the LRDR can be adjusted to reduce the variability attributed to different orchards.

Practical models of LRDR adjustment have used a range of different scaling principles. Morgan (1964) recognised the need for adjustment to tree height. This later became known as the "fruit-wall-area" (FWA) model to indicate the translation from a standard ground area target to a vertical wall area target (Koch, 1993). Byers et al. (1971) were the first to describe the TRV model of adjustment. This was based on the translation from a standard ground area target to the orchard target distributed within the TRV. Subsequent research recognised the need to include the adjustment for area-density (Byers et al., 1984; Sutton and Unrath, 1984; Sutton and Unrath, 1988). More recently, Walklate et al. (2003) established the "tree-area-density" (TAD) adjustment model for use where target size variation is limited as in UK dessert apple production.

Various methods of dose expression have been proposed for orchard spraying products to avoid the confusion between the different models for LRDR adjustment. Bjugstad (1994) proposed a method for orchard spraying in Norway based on a fixed amount of product per 100 m length of tree-row. Furness et al. (1998) proposed an equivalent method of dose expression, called the "unit canopy row" method, for fruit tree and vine spraying in Australia. However, these are not perfect methods of dose expression and require additional adjustment to account for the variation of area-density.

An obstacle to scientific assessment of the different LRDR adjustment models for orchard spraying has been the accuracy and speed of crop sampling to enable estimation of the relevant parameters (Whitney et al., 1989; Planas et al., 1997; Viret et al., 2003; Pergher, 2004). However, the developments of electro-optics technology and commercial-scale manufacturing have resulted in moderately priced LIDAR systems that have been used for making rapid non-invasive measurement of tree-row structure parameters for use with different models of LRDR adjustment (Cross et al., 2001a, b, 2003, 2004; Walklate et al., 2002, 2003, 2004).

The objective of this study is to utilise a database of orchard structure measurements to optimise the practical approximations that may be made for LRDR adjustment to minimise orchard-to-orchard variation of product deposit. Section 2 establishes the generalised relationship between the tree-row structure parameters (i.e. spacing, height, width and area-density) and the adjustment of LRDR. Section 3 describes the method for using LIDAR recordings of crop structure to construct the database. Section 4 presents the results of a 2-year campaign to record the range of different pome fruit orchards and the use of these to compare the relative performance of different approximation models to improve LRDR adjustment practices.

2. Dose-rate adjustment

2.1. Generalised model

Our aim is to express the applied dose rate of a plant protection product δ as an adjustment to the LRDR so that orchard-to-orchard variation of deposit is minimised. To achieve this, we utilise the following model to predict the tree-averaged deposition of spray volume for a given orchard:

$$\mu_W = A\varepsilon/\alpha, \quad (1)$$

where A is the application rate of spray volume (i.e. volume of spray per unit ground area), ε the volume fraction of sprayer output that appears as deposit on the target orchard and α the ratio of target area to ground area (i.e. the crop area index). To avoid errors when using Eq. (1), it is necessary to limit the practical range of spray volume application rates (Walklate et al., 2003). The upper limit of deposition is defined by the spray volume application rate at run-off. The lower limit is much harder to define as an explicit value of volume application rate because it is dependent upon the evaporation during spray transport, which produces changes in droplet size, sufficient to reduce the efficiency of target deposition. To ensure further equivalence with the proposed generic model of spray volume deposit (Walklate et al., 2003), the so-called length-scale of target crop deposition is $L = w\alpha/\varepsilon$ (where w is the spatial interval of spray application and for the purpose of this study is equal to the tree-row spacing).

Multiplying Eq. (1) by the product concentration C gives the following model for product deposition:

$$\mu_P = C\mu_W = \delta\varepsilon/\alpha. \quad (2)$$

From this relationship, it can be appreciated that the slope of product deposit μ_p vs. applied dose rate δ is equal to the local ratio ε/α and this varies with both sprayer adjustment and orchard structure.

Eq. (2) can be manipulated to yield an expression for LRDR adjustment as follows:

$$\delta/\delta^* = (\alpha/\alpha^*)(\varepsilon^*/\varepsilon) \quad (3)$$

to minimise orchard-to-orchard variation of deposit about the efficacious mean deposit (i.e. $\mu_P^* = \delta^*\varepsilon^*/\alpha^*$, where all variables with an asterisk superscript represent the worst-case reference conditions that gives acceptable efficacy for applications at the LRDR).

Expanding Eq. (3) in terms of the classical tree-row parameters (i.e. spacing w, width b, height h and area-density a), where crop area index is $\alpha = ahb/w$, the LRDR adjustment can also be expressed as follows:

$$\delta/\delta^* = (b/b^*)(h/h^*)(a/a^*)(w^*/w)(\varepsilon^*/\varepsilon). \quad (4)$$

This expression is expected to give first-order accuracy without the need for calibrating any linear system that may be used to measure the tree-row structure parameters.

2.2. Minimum spray volume loss model

The generalised model of LRDR adjustment (Eq. (4)) is further constrained by the common requirement to minimise spray volume losses (i.e. $\varepsilon/\varepsilon^* \cong 1$) for uses that reflect best operational practice. Therefore, LRDR adjustment according to the expression

$$\delta/\delta^* = (b/b^*)(h/h^*)(a/a^*)(w^*/w) \quad (5)$$

is suitable for use with environmental-friendly techniques (Matthews et al., 1990; Doruchowski and Holownicki, 2000) and some conventional techniques unless there are significant spray losses (i.e. for low shelter protection conditions near orchard boundaries, in particular, during the early part of the growing season (Richardson et al., 2004)).

Eq. (5) will be used as the basis for subsequent data analysis (Section 4) to establish the relative performance of other simplified LRDR adjustment models of practical interest.

3. Materials and methods

3.1. LIDAR measurement of tree-row structure parameters

The method described by Walklate et al. (2002) was used to determine the tree-row cross-section as a two-dimension map of the threshold interception probability p and $p \geqslant 1\%$ defined the local presence of a tree-row structure, shown in Fig. 2 as the grey-shaded cross-section bh. In accordance with this method, the tree-row parameters were given the following definitions: h maximum height, b width (i.e. the cross-section bh divided by the maximum height) and a average of the area-density distribution within the tree-row cross-section.

A tractor-mounted LIDAR (LMS 200 Sick AG Germany) was used to record the structural details of different orchards from transects along the centre-line between two rows of trees at a height of 1 m above the ground. Each recording gave a standard data set of 5800 rotational scan sequences per orchard transect (ca. 50 m long). Each rotational scan sequence was made up of 200 range measurements between trajectory angle limits of $-50.0°$ and $50.0°$ azimuth. An exception to this was made for large cider apple trees where the LIDAR reference angle was rotated by $30.0°$ to give trajectory angle limits of $-20.0°$ and $80.0°$ azimuth.

3.2. Orchard sites

LIDAR recordings of different pome fruit orchards were made during the two consecutive growing seasons of 2002 and 2003. The farm sites were chosen to represent different growing practices and conditions. Farms E, H, M and R were located in Kent (i.e. an intensive area for pome fruit production in the UK). Farms L and P were located in Hereford and Worcester, respectively. Further planting details of these orchards, including the number of LIDAR transects, have been summarised in Table 1. Farm visits were timed to obtain crop structure recordings before the

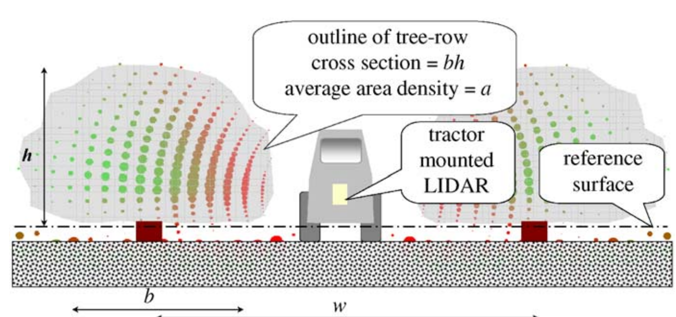

Fig. 2. The tree-row characteristics derived from LIDAR recordings with a tractor-mounted system. The grey-shaded area of the trees represents the tree-row cross-section where the local probability of interception is greater than 1%, after the removal of ground clutter signal below the reference surface (Walklate et al., 2002). A bubble plot is superimposed to represent the distribution of the local area-density (proportional to bubble diameter).

Table 1
Summary of pome fruit orchards at different farms

ID	Variety and type of fruit	Root stock	Approx. year of planting	Tree-row spacing w (m)	Tree spacing along row (m)	Number of LIDAR transects
EA1	Queen Cox apple	M9	1979	3.50	2.40	16
EA2	Queen Cox apple	M9	1979	4.25	3.00	16
HA1	Cox apple	M9	1990	4.30	1.60	16
HA2	Gala apple	M9	1995	4.30	1.60	16
HP1	Conference pear	BA29	1993	4.20	1.85	24
LA1	Cox apple	M9	1988	3.70	1.80	16
LA2	Gala apple	M9	1997	3.40	1.50	8
MA1	Cox apple	M9/MM106	1990	4.00	2.50	16
MA2	Cox apple	M9/MM106	1990	4.00	2.00	16
MP1	Asian pear	Quince A	1990	3.50	2.00	8
MP2	Buckland pear	Quince A	1990	4.20	2.50	8
MP3	Conference pear	Quince A	1958	4.25	4.25	8
PA1	Katy cider apple	MM106	2000	5.30	2.25	8
PA2	Mitchelin cider apple	MM106	1996	5.40	3.00	8
PA3	Dabbinett cider apple	MM106	1996	5.40	3.00	8
PA4	Dabbinett cider apple	MM106	1992	5.50	2.35	8
RA1	Bramley apple	M9/M26	1995	3.60	2.50	24
RA2	Cox apple	M9/MM106	1986	3.60	1.83	8
RA3	Cox apple 2 row bed	M9/MM106	1987	5.30	1.83	8
RA4	Cox apple 4 row bed	M9/MM106	1997	7.00	1.83	8

"end of flowering" and toward the end of "fruit development". Previous research (Walklate et al., 2003) demonstrated that these timings enabled good estimation of the minimum and maximum values of tree-row structure parameters.

4. Results and discussion

4.1. Reference orchard structure conditions

The principle of LRDR adjustment (Section 2) emphasised the need to know the worst-case crop structures (i.e. the reference tree-row parameters: spacing w^*, width b^*, height h^* and area-density a^* in Eq. (5)) that may be associated with acceptable efficacy for full LRDR applications. However, to put these principles into practice would need a specification for the reference structure associated with each plant protection product or a LRDR that represents a standard worst-case structure. As a result of this situation, it has been very difficult to establish the full potential for LRDR adjustment based on grower trials with many common plant protection products (Cross et al., 2004). For future trials of this kind, it may be necessary to limit them to products with uses aimed at integrated pest management (IPM) because these have an established reference structure (e.g. $\mathrm{TRV} = h^*b^*/w^* = 10{,}000\,\mathrm{m}^3\,\mathrm{ha}^{-1}$).

For the purpose of this study, the dessert apple orchard EA1 at "fruit development" (growth stages 77 to 78; Anon, 1989) was selected as the reference structure. The tree-row structure parameters that define this case have been summarised in Table 2. Previous research (Walklate et al., 2003) demonstrated that this structure gave a reasonable approximation to the worst-case for a wide range of dessert and culinary apple orchard measurements at farm E. This structure is also characterised by a $\mathrm{TRV} = h^*b^*/w^* = 11{,}300\,\mathrm{m}^3\,\mathrm{ha}^{-1}$.

Table 2
Reference values of tree-row parameters

ID	Orchard	Spacing w^* (m)	Width b^* (m)	Height h^* (m)	Density a^* (m^{-1})
EA1	Cox apple at the "fruit development" growth stage (i.e. plot CW108 identified by Walklate et al., 2003)	3.50	1.90	2.08	0.86

4.2. Extreme value analysis of tree-row parameters

The maximum and minimum values of LRDR adjustment (Eq. (5)) and the four components of structural adjustment have been listed for each orchard in Table 3. The pear orchard HP1 at fruit maturity represents the worst-case structure for LRDR adjustment ($\delta/\delta^* = 1.49$) due to the combined effects of tree-row width, height and area-density, all exceeding the reference values ($b/b^* = 1.25$, $h/h^* = 1.55$ and $a/a^* = 1.13$). The cider apple orchard PA4 also represented a high LRDR adjustment at fruit maturity ($\delta/\delta^* = 1.38$) due to the combination of a moderate adjustment for area-density

Table 3
The extreme values of tree-row parameter ratios for each orchard type

ID	Spacing ratio (w^*/w)	Width ratio (b/b^*)		Height ratio (h/h^*)		Density ratio (a/a^*)		Dose rate adjustment (δ/δ^*)[a]	
		Min.[b]	Max.[c]	Min.[b]	Max.[c]	Min.[b]	Max.[c]	Min.[b]	Max.[c]
EA1	1.00	0.69	1.05	0.69	1.02	0.34	1.01	0.19	1.00
EA2	0.82	0.70	1.07	0.67	1.02	0.24	0.64	0.10	0.52
HA1	0.81	0.78	1.28	0.77	1.20	0.27	0.86	0.14	0.99
HA2	0.81	0.61	0.99	0.73	1.06	0.20	0.61	0.08	0.45
HP1	0.83	0.72	1.25	0.94	1.55	0.29	1.13	0.22	1.49
LA1	0.95	0.69	1.09	0.71	1.42	0.24	0.76	0.13	0.92
LA2	1.03	0.55	0.89	0.68	1.09	0.24	0.73	0.09	0.65
MA1	0.88	0.52	0.96	0.51	0.74	0.18	0.40	0.04	0.24
MA2	0.88	0.66	1.23	0.61	0.90	0.18	0.41	0.07	0.35
MP1	1.00	0.79	1.09	0.48	0.78	0.25	0.64	0.10	0.49
MP2	0.83	1.06	1.32	0.62	0.96	0.22	0.89	0.12	0.86
MP3	0.82	1.08	1.46	0.61	1.04	0.24	0.76	0.14	0.80
PA1	0.66	0.47	1.00	0.64	1.50	0.12	0.31	0.03	0.31
PA2	0.65	0.52	1.18	1.63	2.09	0.16	0.46	0.14	0.66
PA3	0.65	0.92	1.27	1.64	2.38	0.20	0.57	0.20	0.87
PA4	0.64	1.17	1.41	1.56	2.28	0.30	0.72	0.38	1.38
RA1	0.97	0.71	1.19	0.65	1.16	0.16	0.53	0.08	0.59
RA2	0.97	0.75	0.94	0.86	1.25	0.28	0.65	0.18	0.68
RA3	0.66	1.36	1.52	0.80	1.13	0.31	0.74	0.23	0.84
RA4	0.50	1.49	1.90	0.54	0.63	0.23	0.37	0.09	0.22

[a]Predictions given by Eq. (5) for best operational practice (2.2).
[b]Before the "end of flowering" ($21<GS<67$).
[c]Toward the end of "fruit development" ($77<GS<78$) where GS represents the growth stage key for apple and pear (Anon, 1989).

($a/a^* = 0.72$) and a large adjustment for tree height ($h/h^* = 2.28$).

By contrast with these worst-case examples, the dessert apple orchard RA4 at fruit maturity (i.e. a four-row bed system with a worst-case value for tree-row width ($b/b^* = 1.90$)) gave very low estimates of LRDR adjustment ($\delta/\delta^* = 0.22$), due to the combined scaling effects of low tree height ($h/h^* = 0.63$) and low area-density ($a/a^* = 0.37$). Furthermore, the adjustment for tree-row width was well compensated by the adjustment for tree-row spacing as is common for many large multi-row orchard bed-systems. However, we recognise that the simplicity of Eq. (5) may disguise the practical difficulty of achieving good spray deposit in the centre of a large orchard bed-system.

These results have also made us aware of the potential for reducing the LRDR at the beginning of the growing season, though for practical reasons we have limited the minimum adjustment to 1/4 LRDR in the following analysis based on the convention of the scheme presented by Walklate and Cross (2005).

4.3. Frequency distribution analysis of tree-row parameters

The LRDR adjustments and the component ratios of tree-row parameters have been presented as frequency distribution histograms (Fig. 3). Assuming that the lowest level of practical adjustment is 1/4 LRDR, the results for tree-row parameters span the following ranges of adjustment: 5 to 1 for tree-row height and area-density; 4 to 1 for tree-row width and 2 to 1 for tree-row spacing. However, the combined LRDR adjustment range predicted by

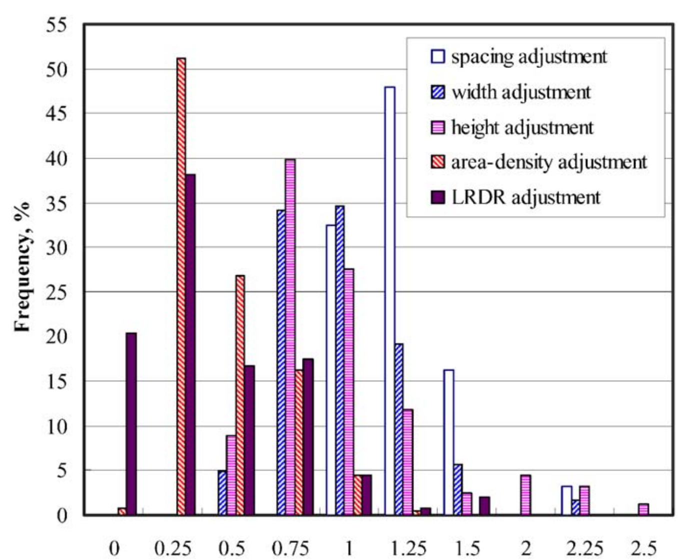

Fig. 3. Histograms of predicted LRDR adjustments and the component ratios of tree-row parameters for the exemplar database of pome fruit orchards. The LRDR adjustment is (δ/δ^*) as predicted by Eq. (5), the spacing adjustment is (w/w^*), the width adjustment is (b/b^*), the height adjustment is (h/h^*) and area-density adjustment is (a/a^*). The bin centres of the histogram are specified with a common spread of $\pm 1/8$. The exception to this is first bin, which spans the range 0 to 1/8.

Table 4
Performance analysis of different approximation models for LRDR adjustment (i.e. $\delta/\delta^* = c_0 + c_1 x$, where x represents different groups of tree-row structure parameters and c's are regression coefficients)

Crop structure dependent variable x	Model ID	Correct prediction of LRDR adjustment (%)[a]	Regression analysis summary parameters[b]		
			r^2	c_0	c_1
0	None	4.5[c]	—	1[d]	—
0		49.6[c]	0.00	0.395±0.039	—
a/a^*	TAD	79.8[e]	0.84	−0.162±0.035	1.284±0.071
h/h^*		56.1[c]	0.36	−0.110±0.090	0.510±0.085
b/b^*		55.3[c]	0.23	−0.182±0.138	0.587±0.136
w^*/w		50.0[c]	0.00	0.434±0.262	−0.046±0.307[f]
$(h/h^*)(a/a^*)$		93.1[e]	0.96	−0.036±0.014	0.944±0.025
$(b/b^*)(a/a^*)$		80.1[e]	0.85	−0.061±0.029	1.018±0.054
$(a/a^*)(w^*/w)$		72.8[c]	0.69	−0.073±0.045	1.269±0.106
$(b/b^*)(h/h^*)$		58.9[c]	0.48	−0.025±0.061[f]	0.421±0.054
$(h/h^*)(w^*/w)$	FWA	55.3[c]	0.47	−0.309±0.098	0.863±0.115
$(b/b^*)(w^*/w)$		43.9[c]	0.35	−0.485±0.155	1.085±0.187
$(h/h^*)(a/a^*)(w^*/w)$		88.2[e]	0.93	−0.037±0.018	1.134±0.038
$(b/b^*)(h/h^*)(a/a^*)$		87.0[e]	0.94	0.033±0.015	0.750±0.024
$(b/b^*)(a/a^*)(w^*/w)$		82.1[e]	0.82	−0.048±0.031	1.184±0.070
$(b/b^*)(h/h^*)(w^*/w)$	TRV	66.3[c]	0.68	−0.222±0.057	0.765±0.065

The exact values of LRDR adjustment needed to minimise orchard-to-orchard variation of deposit is based on Eq. (5). Tree-row structure parameter measurements were derived from LIDAR recordings of different orchard types described in Table 1 (representing a sample population of 248 orchard transects).
FWA—fruit-wall-area model, TAD—tree-area-density model, TRV—tree-row-volume model.
[a]The percentage of correctly predicted adjustments to within a tolerance error band ±1/8th of LRDR and the summary results of an F-test (MSExcel 2003 two-sample variance analysis tool to test equality between variances of predicted LRDR adjustment at a significance level of rejecting the true hypothesis Alpha = 0.05).
[b]Results of regression analysis tool (MSExcel 2003) distribution means are equal.
[c]Variances are not equal.
[d]Regression analysis not applicable.
[e]Variances are equal.
[f]Regression coefficient estimate is not significantly different to zero.

Eq. (5) was 6 to 1 (i.e. only just larger than the range given by either tree-row height or area-density). Thus the following analysis is set out to further quantify the redundancy in the use of Eq. (5).

4.4. Ranking approximation models for dose-rate adjustment

In all, 15 different approximation models of LRDR adjustment were formulated for testing against Eq. (5) and the results summarised in Table 4. The approximation models were formulated by using a typical data fitting equation used by others (i.e. $\delta/\delta^* = c_0 + c_1 x$, where x represents any group of crop structure parameters (column 1) and c's are the regression coefficients (columns 5 and 6)). The approximation models have been ranked: according to the number of empirical inputs; the number of different tree-row structure parameters needed to define x and according to the percentage of correctly predicted adjustments to within a tolerance error band ±1/8th of LRDR (column 3).

For this population of orchard samples and reference orchard conditions, 5% were correctly predicted at the full LRDR and 50% were correctly predicted at 2/5 LRDR. Other published approximation models of practical importance gave an improvement in the number of correctly predicted adjustments (i.e. 55% for the FWA model, 66% for the TRV model). However, the agreement with Eq. (5) was not significant in all these cases.

Various models that included the scaling effects of tree-row area-density gave significant agreement with Eq. (5) and the following models gave the best improvements in their class for the number of correctly predicted adjustments (i.e. 80% for the TAD model and 93% for the combined adjustment for tree-row height and area-density). These results support previous observation based on the comparisons of different models with spray deposit measurements (Walklate et al., 2002).

5. Conclusions

This study has presented a method for determining the optimum label-recommended dose rate (LRDR) adjustment for a given population of crop structures defined by a given database of tree-row parameters. In this case, data were derived from LIDAR recordings of different pome fruit orchards to minimise the uncertainty of crop structure measurements.

By applying various truncation simplifications to the exact model for LRDR adjustment, assuming minimum spray volume loss (Eq. (5)), it was shown that area-density and height adjustments were the best crop structure parameters on which a simplified scheme for pome fruit spraying could be based. However, further research is required to establish the effects of operational practices that might change the assumptions we have made.

To support the principle of dose-rate adjustment, a more transparent registration system is needed that removes the guess work. The first stage is to determine and agree reference crop standards for determining the LRDR. Standardising the reference conditions for efficacy trials is very important. Clearly, when conducting efficacy trials, use of crops with adequate levels of pressure from the target pest or disease is of paramount importance. However, to improve understanding of the dose–efficacy relationship of the test products, information is needed so that the crop structure can be related to a standard. The methodology described in this paper could be used to help establish new pesticide regulatory standards for tree and bush crop spraying, and indeed any other crop.

Communication of reference crop structure information is essential to improve the precision of LRDR adjustment. As a tentative suggestion to satisfy short-term needs for pome fruit spraying in the UK, a suitable reference structure is represented by an orchard with a small row spacing (ca. 3.5 m), high planting density, and a tree height of 2 m at the "full-leaf" growth stage. Furthermore, this description might be more easily understood by growers than the equivalent tree-row-volume (TRV) standard (ca. 10,000 $m^3 ha^{-1}$), which ignores the important scaling effects of area-density.

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