Pesticide Dose Adjustment in Vineyard Spraying and Potential for Dose Reduction

G. Pergher and R. Petris

Department of Agriculture and Environmental Sciences, University of Udine,

Viale delle Scienze 208, 33100 Udine - Italy

gianfranco.pergher@uniud.it; raffaela.petris@uniud.it

ABSTRACT

The adjustment of pesticide dose rates according to canopy size and leaf area density is not encouraged by current label formulations. However, experimental evidence shows that the application of a constant dose per unit ground area consistently results in average foliar deposits that are inversely proportional to the leaf area index (*LAI*) of the crop. Several methods for dose rate adjustment have been proposed, including the CH, LWA, TRV, and TAD models. The objective of this paper was to analyse the potential of the LWA (Leaf Wall Area) method for reducing deposit variability in espalier vineyards. A set of 42 deposition tests was analysed, performed during 1993 to 2005 using a uniform methodology for canopy and spray deposit assessment. Normalised deposits were calculated, assuming a constant dose either per unit ground area, and per unit LWA, respectively. The results showed that the LWA method has the potential of reducing deposit variability, compared to the fixed dose, conventional method (C.V. = 36% and 13%, respectively). Variations in canopy width and leaf area density scarcely affected mean deposits as long as the leaf layer index was *LLI* < 4. A decrease in mean deposits could be observed only for very thick and wide canopies with 4 < *LLI* < 6, which were otherwise not recommended, based on best agronomical practice.

Keywords: Vineyard, sprayer, dose rate, adjustment, leaf wall area, Italy

1. INTRODUCTION

One way of reducing the environmental risks associated with broadcast spraying in orchards and vineyards is to correctly adjust pesticide application rates to the actual needs of the crop, in order to avoid excessive dosages, while ensuring necessary crop protection. This is not encouraged by current label recommendations, which generally give only the maximum allowable (legal) dose rate per unit ground area. Although some labels may recommend different doses depending on the crop, the growth stage, the degree of disease pressure, or other factors, no information is generally reported on how to adjust dose rates to account for different canopy size, shape, or leaf area density. However, experimental evidence shows that the application of a constant dose per unit ground area consistently results in average foliar deposits that decrease, when the leaf area index (*LAI*) of the crop increases. Figure 1 summarises nearly 400 deposit measurements performed in vineyards and orchards (Rüegg *et al.,* 2001; Siegfried *et al*., 2005; Pergher, 2007). To account for different dose rates applied in the field tests, we normalised the deposits in Figure 1 using the equation:

$$d_N = d\,\frac{Q_N}{Q} \qquad (1)$$

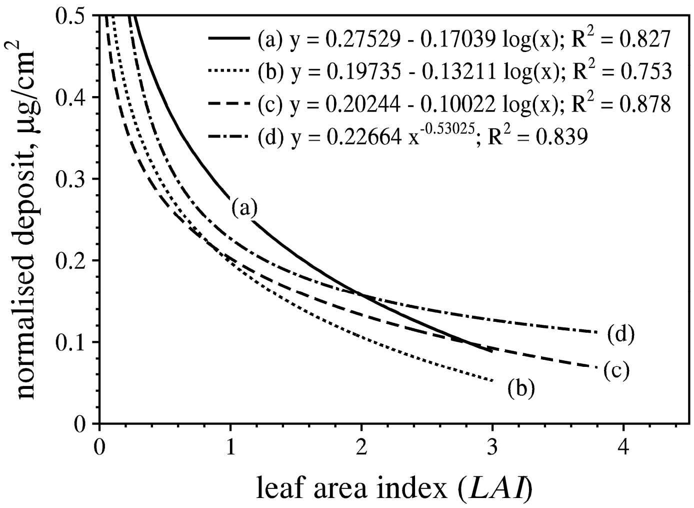

Figure 1. Regression of the mean normalised foliar deposit over the leaf area index (LAI). vineyard, 90 tests on new sprayers (2001-02), Siegfried *et al*. (2005); (b) vineyard, 163 tests on used sprayers (1999-2000), Siegfried *et al*. (2005); (c) apple orchards, 102 tests, Rüegg *et al*. (2001); (d) vineyard, 42 tests (1993-2005), Pergher (2007).

where: Q, in µg/cm^2 ground area, is the tracer (or pesticide) application rate; d, in µg/cm^2 leaf area (including both leaf sides), is the measured foliar deposit; Q_N, equal to 1 µg/cm^2, is a fixed application rate we chose for normalisation; and d_N, in µg/cm^2, is the normalised deposit.

Although all of the regression curves in Figure 1 show the same trend, some differences may be observed, depending on the crop, or the set of sprayers used. More particularly, vineyard tests (a) and (d) were performed using new sprayers, under controlled conditions, while tests (b) mostly included aged (in use) sprayers, under conditions more representative of average agricultural practice. In any case, Figure 1 shows that variations in spray deposits by a ratio of 1 : 6 may be expected in apple orchards and vineyards, if the dose rates are not adjusted to account for crop variability.

Based on the above evidence, it has been suggested that pesticide doses might be reduced in orchards and vineyards with small canopies, low leaf area density, and at the earlier growth stages, thus reducing the risks associated with higher spray drift (Balsari and Scienza, 2003), and phytotoxicity. Several methods for dose rate adjustment in three-dimensional crops have been proposed so far (Martin *et al.*, 1998; Rüegg *et al.*, 2001; Koch and Weisser, 2002; Walklate *et al*., 2003; Table 1). The objective of this paper is to discuss which method may be best suited for practical application in vineyards, particularly under Italian conditions.

2. MODELS FOR DOSE EXPRESSION

In general, a method for dose expression can be described by a model such as: $Q \propto p$, where Q is the pesticide dose rate per unit ground area, and p is a crop structure parameter (Table 1).

Before discussing the models proposed so far, it may be useful to approach the problem from a general point of view. By definition, the average foliar deposit (d, in µg/cm^2 leaf area) is given by:

$$d = 10^{-2} \frac{Q\varepsilon}{2LAI} \quad (2)$$

where: Q, in g/ha, is the application dose rate; ε is the spray fraction deposited on the canopy; LAI is the Leaf Area Index; and factor 2 is included to account for both leaf sides.

Based on equation (1), the application rate (Q_0) needed to obtain a given average deposit (d_0) may be expressed as:

$$Q_0 = 2 \cdot 10^2 d_0 \frac{LAI}{\varepsilon} \quad (3)$$

Application of equation (3) for dose rate adjustment would be highly impractical, because both LAI and ε are very difficult to determine for the farmer, under field conditions. A different expression is possible considering that:

$$LAI = \frac{a\,w\,h}{b} \quad (4) \qquad \text{so that:} \qquad Q_0 = 2 \cdot 10^2 d_0 \frac{a\,w\,h}{\varepsilon\,b} \quad (5)$$

where: a, in m²/m³ (leaf area/canopy volume), is the average leaf area density; w, in m, is the average canopy width; h, in m, is the height interval of the canopy; and b, in m, is the distance between rows.

Table 1. Models for dose expression.

Common name	Crop structure parameter	Model	Reference	true if
Standard method	none	$Q = k$	Most pesticide labels	$\frac{a\,w\,h}{\varepsilon\,b} = k$
Crown height	h	$Q \propto h$	Martin *et al.*, 1998; some labels (Germany)	$\frac{a\,w}{\varepsilon\,b} = k$
Leaf Wall Area (*LWA*)	$LWA = 10000\frac{h}{b}$	$Q \propto \frac{h}{b}$	Koch and Weisser, 2002	$\frac{a\,w}{\varepsilon} = k$
Tree Row Volume (*TRV*)	$TRV = 10000\frac{w\,h}{b}$	$Q \propto \frac{w\,h}{b}$	Sutton and Unrath, 1984; Rüegg *et al.*, 2001	$\frac{a}{\varepsilon} = k$
Tree Area Density (*TAD*)	$TAD \propto a$; derived from LIDAR measurements	$Q \propto a$	Walklate *et al.*, 2003	$\frac{w\,h}{\varepsilon\,b} = k$
None (general)	$LAI = \frac{a\,w\,h}{b}$	$Q \propto \frac{a\,w\,h}{\varepsilon\,b}$	this paper	(always)

Where: Q, in g/ha, is the application rate; a, in m^2/m^3 (leaf area per unit canopy volume), is the leaf area density; b, in m, is the row spacing; ε is the spray fraction deposited on the canopy; h, in m, is the height interval of the canopy; k is a constant; LAI (leaf area per unit ground area) is the Leaf Area Index; w, in m, is the canopy width.

While some of the parameters (*w, h*, *b*) in equation (5) are easy to determine, some others (*a*, ε) still are not. However, equation (5) represents a general expression for dose rate adjustment. In fact, each of models proposed so far is a particular case of this general equation; or, a simplified expression that may be acceptable under some assumptions or conditions (reported in Table 1, last column).

The Crown Height model (Martin *et al.*, 1998) only takes one parameter into consideration, canopy height. Because of its simplicity, this method of dose expression has already been adopted for some pesticide labels, e.g. in Germany. However, the model will hold only if the remaining parameters are constant, which might be true just in relatively small and uniform orchard areas.

The Tree Row Volume model (Sutton and Unrath, 1984; Rüegg *et al*., 2001) uses three parameters (*w, h*, *b*). Still, it is simple enough, and practical application in several countries, including Switzerland (Rüegg *et al*., 1999b), has been reported. Experimental evidence showed that average pesticide savings of 15% to 50% were possible using this method, while the efficacy of pest control was generally similar, or even superior, as compared both to the standard method (constant dose rate per unit ground area) and to the Crown Height model (Rüegg *et al*., 1999a; Rüegg *et al*., 2001; Steffek *et al*., 2000). A similar concept (Unit Canopy Row model) has been proposed by Furness *et al.* (1998). This model is based on the determination of a canopy retention volume, or the maximum volume of spray liquid that can be retained by the canopy at the point of first run-off (e.g. 30 l/1000 m^3 canopy volume in vineyards, Furness *et al*., 1998). The resulting dose rates are proportional to the canopy volume, and three parameters (*w, h*, *b*) are needed for calculation (Barani *et al*., 2008).

The Tree Row Volume model may be considered as a simplification of equation (5), assuming that parameters *a* (leaf area density) and ε (fraction of spray deposited on the canopy) are irrelevant; or, as an alternative, that their ratio a/ε may be considered as a constant, for a sufficiently wide range of practical conditions. In fact, the last assumption seems to be supported by some experimental evidence. Using the data from 13 deposition test performed in stone fruit orchards, reported by Rüegg *et al.* (1999a), we analysed the relationship between ε and *a*. Both parameters were strictly correlated ($R^2 = 0.849$), and the relationship was one of nearly linear proportionality, with: $\varepsilon = k\ a$ (where $k = 42.172$). If the ratio a/ε can be regarded as a constant, then the Tree Row Volume model is an equivalent of equation (5).

However, the above assumption might not be true under all situations. For one thing, since the fraction retained by the canopy (ε) cannot exceed 100%, the regression line must be bending downwards, above a certain leaf area density; and in any case, more experimental evidence is probably needed. It is possible, however, that most of the practically relevant conditions are actually included in this range of nearly direct proportionality, and this might explain the good results reported so far from the application of the Tree Row Volume method.

The Tree Row Density model (Walklate *et al*., 2003) appears to be a strong simplification of equation (5), since only one parameter, tree area density (*TAD*), is used (although the concept of "tree area density" is a more comprehensive one than that of "leaf area density", it may be assumed that $TAD \propto a$, as reported in Table 1). The peculiarity of this approach is in the fact that a three-dimensional scanning equipment (LIDAR) is used for canopy assessment. However, the identification of the correct spraying strategy, based on a "pictographic key" (or, a series of canopy pictures associated with dose rate adjustment factors), as suggested by

Cross and Walklate (2008) might involve a more subjective judgment than, for instance, the direct assessment of tree height, or tree row volume, made by the farmer himself. On the other side, a very large number of LIDAR assessments will be necessary to characterise all relevant canopy structures at different growth stages; which seems impractical particularly under Italian conditions, because of the wide variety of fruit crops, cultivars, training systems, planting distances and so on, even inside the same agricultural farm.

The Leaf Wall Area model (Koch and Weisser, 2002) only uses two parameters, tree height (*h*) and row distance (*b*). It may be considered as a particular case of the Tree Row Volume method, under the assumption that the canopy width (*w*) is either constant or not relevant. The definition "leaf wall area" is normally applied to the (one-sided) area of the fruit wall, or foliage wall, in a crop which mainly develops in a vertical plane (such as espalier fruit trees, or vineyards). In this case, the term "leaf layer index" (*LLI*) has been proposed (Pergher and Petris, 2007) to define the ratio of leaf area to (one-sided) wall area:

$$LLI = \frac{LAI}{h\,b} = a\,w \qquad (6)$$

(all symbols with the same meaning as anywhere in this paper).

In a study to analyse the relationship between different canopy parameters and the deposition efficiency of a vineyard sprayer, we found (Pergher and Petris, 2007) that the fraction of spray retained by the canopy (ε) was directly proportional to the leaf layer index (*LLI*) as long as *LLI* was < 4. If this is true and can be generalised, then the expression: $a\ w\ /\ \varepsilon$ may be considered as a constant; then, the Fruit Wall Area model is equivalent to equation (5), at least for all practical purposes discussed in this paper.

2. THE CASE OF VINEYARDS

Historical and local traditions, as well as variability in climate and soil conditions, or the need of more intensive mechanisation of harvesting and pruning, have led to a variety of vine growing systems in Italy. Vine canopies may be grown freely (Alberello), or trained to develop in a (nearly) horizontal plane (Tendone, Pergola), or in a vertical plane (espalier, or vertical trellises); the last including systems with free shoots (Geneva Double Curtain, Single Curtain), vertically positioned shoots (Guyot, Spur Cordon, Capovolto), or a combination of both (Sylvoz, Casarsa). This makes it difficult to define a general rule for sprayer calibration, and to account for variability in canopy height and width, leaf density, and row distances. Even so, the Tree Row Volume (Siegfried *et al.*, 2005) and Leaf Wall Area (Koch and Weisser, 2002) methods have been proposed for vertical trellised vineyards, which account for more than two thirds of all vineyard area in Italy.

However, application of the Tree Row Volume in vineyards seems difficult. In fact, the very concept of canopy volume may be questioned in this case. Objective assessment of canopy height and width is only possible immediately after top and side trimming, which cannot, of course, be performed before each single spray application. In most cases, canopy height and width will change continuously along the row, particularly when the shoots are let to develop freely (Geneva Double Curtain and Single Curtain systems; and, to some extent, Sylvoz and Casarsa). Even in those systems with vertically positioned shoots (Guyot, Spur Cordon, Capovolto), there are problems. A typical case is when vertical shoot positioning, which is a very time-consuming operation, has yet to be performed for some part of a vineyard; application of the TRV method would lead, in this case, to different doses, even if the leaf area were, very probably, the same.

In fact, all of these problems can be solved, if the definition of "canopy height" is changed to "height interval of the over sprayed zone" (as suggested by Koch and Weisser, 2002); and, if canopy width is not taken into consideration at all, as in the Leaf Wall Area model.

3. TESTING THE LWA MODEL IN VINEYARDS

To find out if this model can be useful to reduce deposit variability in espalier vineyards, we decided to test the assumption that the expression: $a\ w\ /\ \varepsilon$ might be considered as a constant on a wider sample of deposition data than in our previous study (Pergher and Petris, 2007). This data set was the same as the one used to determine regression equation (d) in Figure 1 (Pergher, 2007). It included 42 deposition tests, performed during 1993 to 2005. All field tests were performed with the same methodology on four to six spatially randomised replicates, using either a fluorescent dye (Brilliant Sulpha Flavine) or a food dye (Tartrazine) as a tracer, to determine the mean deposit per unit leaf area (in $\mu g/cm^2$), and the spray fraction retained by the canopy (in % of the applied dose). The tests included different training systems (Casarsa, Spur Cordon, Guyot), row distances (2.0 m to 3.6 m), and growth stages (from BBCH 13, third leaf unfolded, to BBCH 81, beginning of ripening; Lorenz *et al*., 1994); thus, the height of the sprayed zone ranged from 0.7 m to 2.2 m. Different sprayers were used, including air-assisted sprayers (standard, with air conveyor, and multi-row), and compressed-air sprayers. Most of these tests were originally intended to compare different sprayer settings, so that the operational parameters also differed, including: spray volumes (67 to 1355 l/ha), forward speeds (5.1 to 9.3 km/h), and air flow rates (zero to 9.4 m^3/s).

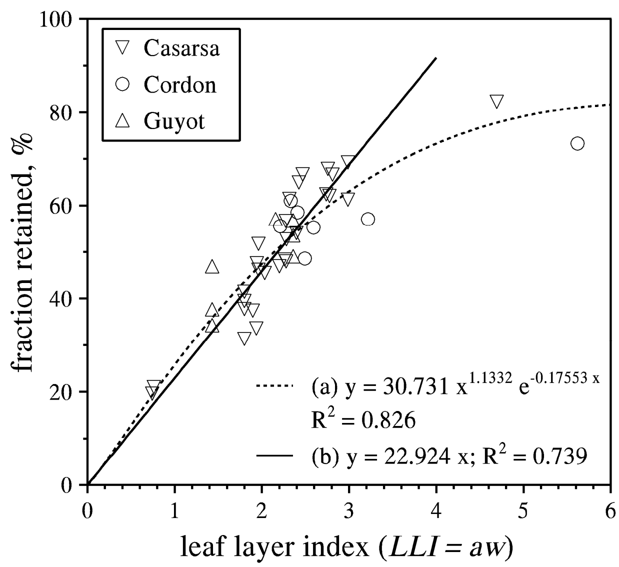

Figure 2. Regression of the spray fraction retained by the canopy vs. the leaf layer index (*LLI*) in vineyards. (a) all data (42 tests); (b) data points with *LLI* < 4 (40 tests).

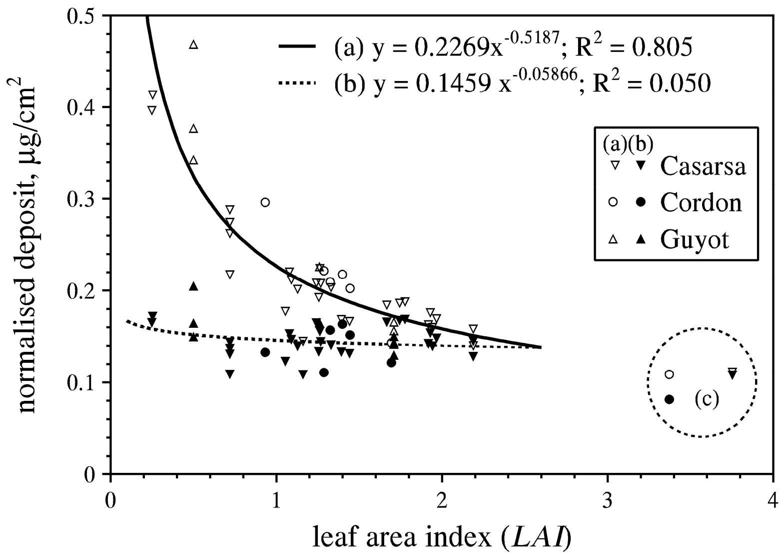

Figure 3. Regression of the normalised foliar deposit vs. the *LAI.* (a) fixed dose per unit ground area; (b) LWA-adjusted dose; both regressions calculated from the 40 tests with LLI<4); (c) two field tests with 4<LLI<6.

To test the above assumption that $a\ w\ /\ \varepsilon$ may be considered as a constant, we calculated the regression of the spray fraction retained by the canopy versus the leaf layer index (curve (a) in Figure 2; R^2 = 0.826). Although the relationship was not linear, it could be assumed to be linear if *LLI* < 4. In fact, the best fit equation (not shown in Figure 2), calculated from the 40 data points with *LLI* < 4, was: ε = 19.946 LLI + 6.8697 (R^2 = 0.756). However, assuming a relationship of direct proportionality, the data could be fitted by the equation (line (b) in Figure 2): ε = 22.924 *LLI* (R^2 = 0.739), with only a small decrease in the percentage of variability accounted for by the regression.

This seemed to support the assumption that the LWA model could be considered as an equivalent of general equation (5). Thus, we calculated normalised foliar deposits for the 40 tests with *LLI*<4, using equation (1) and assuming either a constant application rate per unit ground area (Q_N = 1 µg/cm^2), or a variable rate, proportional to the *LWA* in the vineyard (Q_{LWA}):

$$d'_N = \frac{d}{Q} Q_{LWA} \qquad \text{(1b)} \qquad \text{where} \qquad Q_{LWA} = Q_N \frac{LWA}{LWA^*} \qquad \text{(7)}$$

and where: *LWA*, in m^2/ha, is the actual (one-sided) leaf wall area in each field test; while *LWA**, equal to 8000 m^2/ha, is the maximum leaf wall area in our data set.

Although the resulting normalised deposits (Figure 3) actually represent tracer deposits, they may represent pesticide deposits if Q_N is considered to be a pesticide rate, and more particularly the maximum allowed (label) pesticide rate. Equation (7) ensures that the LWA-adjusted rate, Q_{LWA}, will never exceed the label rate, Q_N, even at maximum *LWA*.

The analysis showed that LWA-adjusted deposits, (b) in Figure 3, were nearly independent of the *LAI*, and much less variable than the fixed-dose deposits, (a) in Figure 3 their coefficients of variation being 13%, and 36%, respectively. Figure 3 also shows that dose rate reductions between 8% and 58% (average: 29%) may be expected using the LWA method. However, the method may not ensure sufficient foliar deposits in vineyards with very thick and wide canopies, with $4 < LLI < 6$ (two tests, Figure 3). In this case, a correction factor might be recommended; on the other hand, however, such canopies are not generally recommended, based on good agricultural practice, because of the risk of decreasing grape quality.

4. CONCLUSIONS

The analysis performed in this paper showed that all existing models for dose rate expression can be considered as particular cases of a general model, described by equation (5). TRV (Tree-Row-Volume) showed a good potential to reduce spray deposit variability, particularly in pome and stone fruit orchards. However, because of the underlying assumptions, the method might not ensure sufficient deposition in canopies with very high leaf area density (e.g. in citrus trees).

For vineyards trained to a vertical wall (espalier vineyards), the Leaf Wall Area (LWA) model may be preferred, to avoid the assessment of canopy width, which is subjective in most cases, and rarely reliable. The analysis performed on a data set from 42 field tests confirmed the potential of this model for a substantial reduction of deposit variability, and consequently of pesticide dose rates. Since these results rely entirely on deposition data, they need to be confirmed by biological efficacy tests before the LWA method may be proposed for practical application. Field tests might also suggest which correction factors might be used, for instance, to account for different crop sensitivity to some pests, depending on the growth stage or time of the season.

Another condition for practical application of a dose-adjusting method will be the good efficiency of the spraying equipment used. As shown in Figure 1, older sprayers and those that are not properly calibrated will give lower deposits on the canopy than new, well-adjusted ones. Because of this, a full implementation of sprayer inspection and calibrating procedures will be essential for the success of any method for dose rate adjustment.

5. REFERENCES

Balsari, P. and A. Scienza. 2003. *Training systems of the vine and methods for pesticide application*. Bayer CropScience, Milano, (in Italian).

Barani, A., Franchi, A., Bugiani, R. and A. Montermini. Efficacy of Unit Canopy Row spraying system for control of European vine moth (Lobesia botrana) in vineyards. *Agricultural Engineering International: the CIGR Ejournal.* Manuscript ALNARP 08 005, Vol. X . May, 2008.

Cross, J. and P. Walklate. The UK PACE Scheme for Adjusting the Dose to Suit Apple Crops. *Agricultural Engineering International: the CIGR Ejournal.* Manuscript ALNARP 08 003, Vol. X . May, 2008.

Koch, H. and P. Weisser. 2002. Expression of dose rate with respect to orchard sprayer function. *Advances of Applied Biology,* 66: 353-358.

Furness, G.O., P.A. Magarey, P.H. Miller and H.J. Drew. 1998. Fruit tree and vine sprayer calibration based on canopy size and length of row: unit canopy row method. *Crop Protection*, 17 (8), 639-644.

Lorenz, D., D. Eichorn, H. Bleiholder, R. Klose, U. Meier and E. Weber. 1994. Phänologische Entwicklungsstadien der Weinrebe (Vitis vinifera L. ssp. vinifera). Codierung und Beschreibung nach der erweiterten BBCH-Skala. *Viticulture and Enology Science,* 49: 66–70.

Martin, J., J. Siebers, H.T. Laermann and E. Heinrich-Siebers. 1998. Studies on the distribution of spray deposits in the crown of apple trees of different crown volume as a contribution to the harmonisation of dosage of plant protection products. *Nachrichtenblatt der Deutschen Zeitschrift für Obst- und Weinbau,* 135: 1-12 (in German).

Pergher, G. 2007. Methods for adjusting pesticide dose rates to the canopy parameters in orchards and vineyards. *Proceedings, Incontri Fitoiatrici.* 15-19 Torino, 28 February - 2 March (in Italian).

Pergher, G. and R. Petris. 2007. Canopy structure and deposition efficiency of vineyard sprayers. *Journal of Agriculture Engineering* - *Rivista di Inegneria Agraria,* 2: 53-60.

Rüegg, J., O.Viret and U. Raisigl. 1999a. Adaptation of spray dosage in stone-fruit orchards on the basis of tree row volume. *Bulletin OEPP*, 29(1/2):103-110.

Rüegg, J., W. Siegfried and E. Holliger. 1999b. Adaptation of spray volume as well as dosage of pesticides to the tree row volume for pome and stone fruit. *Schweizerische Zeitschrift für Obst- und Weinbau*, 135(12): 1-12 (in German and French).

Rüegg, J., W. Siegfried, U. Raisigl, O. Viret, R. Steffek, H. Reisenzein and U. Persen. 2001. Registration of plant protection products in EPPO countries: current status and possible approaches to harmonization. *Bulletin OEPP,* 31(2): 143-152.

Siegfried, W., M. Sacchelli, O. Viret, R. Wolhauser, U. Raisigl, B. Huber, R. Ipach and G. Bäcker. 2005. Blattflächenbezogene Dosierung von Pflanzenschutzmittel im Rebbau. II Teil: Gerätetechnik, Wirkstofflagerung und Wirkung gegen Pilzkrankheiten. *Zeitschrift für Obst- und Weinbau*, 6: 9-13.

Steffek, R., H. Reisenzein and U. Persen. 2000. Tree-Row-Volume, a new way for the registration of plant-protective agents in orchards? Results of 3-year field trials in Austrian apple orchards. *Acta Horticulturae,* 525: 195-200.

Sutton, T. B., and C. R. Unrath. 1984. Evaluation of the tree-row-volume concept with density adjustments in relation to spray deposits in apple orchards. *Plant Disease*, 68: 480-484.

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