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Dosage of plant protection products adapted to leaf area index in viticulture

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Abstract

The efficacy of plant protection products depends on many factors. Among them, the dose of active ingredient, the size of deposits, the number of deposits and the dose per deposit on the leaf surface are very important elements for successful control of diseases. For crops, such as grapevine which develops a large canopy within a relative short period of time, the dosage is generally adapted to the growth stage of the vine or a unique dose is applied during the whole growing season. These can result in over- or under-dosage of plant protection products, with economic and environmental impacts, reduced efficacy or increased risk of resistance.

The aim of the new dosing concept is to apply the amount of product necessary to control diseases and pests and avoid over- and under-dosing. Key elements of the leaf area index based dose model are knowledge of the leaf surface at the day of application, the application quality of the equipment and the dose–response curve of the applied product.

Based on several field experiments and measurements on different grape varieties, a correlation between the effective leaf area, the shoot length and the vine row volume (VRV) was established and used as an indirect method to determine the leaf area index (LAI). Dose–response experiments for folpet and azoxystrobin against downy mildew allowed the amount of active ingredient per leaf area unit for good efficacy to be determined. The average LAI-dependent deposit capacities of different commercial sprayers were measured in farm experiments and a dosage table established to adapt the amount of active ingredient to the LAI. Applying the LAI-adapted dosage, no differences in efficacies could be obtained on season-long spraying programs with commonly used fungicides against downy and powdery mildews, compared to recommended dosages. The data demonstrate that independently of the growth stage of the vine, a more or less constant amount of active ingredient, obtained from the dose–response experiments, was deposited on the leaves using the LAI-adapted dosage, in contrast to the standard dosage.

Keywords: Grapevine; Crop adapted spraying; Leaf area index (LAI); Vine row volume (VRV); Deposit and distribution of active ingredient; Biological efficacy; Powdery and downy mildew

1. Introduction

Worldwide the large majority of the grape-growing area is planted with cultivars of *Vitis vinifera* L. sensitive to powdery (*Erysiphe necator* [Schw.] Burr.) and downy mildew (*Plasmopara viticola* [Berk. & Curt.] Berl. & De Toni). The regular use of fungicides during the whole growing period is the only way to control these fungal diseases.

Until the late 1980s the registered concentration (%) of plant protection products in viticulture was based on 2000 l/ha. Later the amount of product was indicated in kilograms or litres of product per hectare in addition to the concentration, calculated for water volumes between 600 and 1600 l/ha, respectively, 150 and 400 l/ha for air-blast

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sprayers, which correspond to a four times higher concentration. This was very confusing for the growers and led to a false dose calculation. The dosage of plant protection products in Switzerland and Germany is growth stage-dependent (Eichhorn, 1984) although currently the registered dose is still indicated as a concentration and amount of product per hectare. On the other hand, in France and Portugal registration is based on a dose per hectolitre, whereas in Italy only a concentration is registered without indication of the water volume (Rüegg et al., 2001). This situation presents a major problem when comparing experimental data obtained in different countries and presented in registration dossiers.

Grapevine growth starts without any leaves and ends with a large canopy. The resulting leaf area to be treated can change from zero to over 23,000 m^2/ha each season. Therefore, plant protection products and volume application rates based on a fixed rate per hectare over-treat early season foliage, but may under-dose late season foliage. Plant densities in Switzerland can vary from less than 5000 to over 12,000 plants per hectare, depending on the pruning system whereas plant densities in key wine-growing countries (Italy, Spain, France, Germany) are typically in the range of 1500–5000 plants per hectare. These differences demonstrate that the dosage of plant protection products should be adapted to the leaf area present on the day of application and not to the ground surface or to the water volume used.

This paper describes firstly a method for the indirect determination of the leaf area based on field measurements. Secondly a leaf area-based dosage system is proposed for plant protection products, particularly for fungicides, considering the deposit quality of different spraying equipment, as well as the dose–response curves of some active ingredients. Finally, biological efficacy of field experiments using the leaf area adapted dosage system is reported.

2. Material and methods

2.1. Experimental plots

The experiments and measurements were performed between 2000 and 2004 in three research institutes in Germany and two in Switzerland on the main grape varieties for the respective area (Table 1). Technical details of the different sprayers used are also described in Table 1. The Lipco recycling tunnel sprayer was developed to reduce drift and improve application quality since two large panels surround the vine row. The axial air-blast sprayer can be considered as reference equipment in Switzerland and Germany. All the equipment used was calibrated before each application using the Caliset method (Raisigl and Felber, 1991; Viret, 2005). The size of the experimental plots was at least 1000 m^2 for air-blast sprayers, 500–750 m^2 for the recycling sprayers. Typically five rows were sprayed, but leaves and grape bunches for the deposit measurements were only taken from the center row.

Between 1990 and 2000 a database was developed using deposit measurements from on-farm experiments in western Switzerland (Vetroz, Leytron, Conthey), eastern Switzerland (Wädenswil, Maienfeld, Walenstadt) and Germany (Geisenheim) with commercial axial, reverse-axial, pneumatic and recycling tunnel sprayers used by the growers and by the research institutes in Switzerland and Germany. These data established the mean deposit of representative commercial sprayers according to the leaf area index during the growing season.

2.2. Leaf area measurements

Leaf area analyses were performed during the growing period of the vine at least seven times (BBCH stages 13, 16, 19, 61, 69, 75, 81). For each time and grape cultivar 15–20 shoots from different plants were taken at random.

Table 1
Experimental plots (2000–2004) in Switzerland (CH) and Germany (D) and technical details on the spraying equipment used

	Wädenswil (CH)	Perroy (CH)	Freiburg i.Br (D)	Neustadt a. W. (D)	Geisenheim (D)
Cultivars	Müller-Thurgau, Pinot noir	Chasselas	Müller-Thurgau, Pinot noir	Müller-Thurgau	Riesling
Rootstocks	5C	3309	5BB	5BB	SO4
Planting distances (m)	1.9×0.9	2.2×0.8	1.7×1.5	1.8×1.2	1.8×0.8
Plants per ha	5848	5682	3920	4579	6944
Trellising system	Cane pruned	Cane pruned	Cane pruned	Cane pruned	Cane pruned
Sprayer	Air-blast sprayer Fischer Turbo 561-H	Air-blast sprayer Fischer Minitrac 500-H	One row tunnel-recycling Lipco	One row tunnel-recycling Lipco	Tangential sprayer Holder QU20
Air assistance	Axial	Axial	No air assistance	No air assistance	Tangential
Air flow rate (m^3/h)	14,000	12,000			20,000
Nozzle type	Teejet 80-015	Albuz ATR yellow	Teejet TP 65-01	Teejet-015	Albuz ATR yellow
Number of nozzles	4/6/8	4/6/8	4/6/8	4/6/8	4/6/8/10
Pressure (bar)	5	5	10	10	10
Traveling speed (km/h)	5	4	2.8	3.3	5.6
Spray volume (l/ha)	200–400	100–400	400–800	400–800	200–600

Alternatively all the shoots from three plants were also collected as a comparison. Shoot length, the number of leaves per shoot, including laterals were assessed and the leaf area per shoot measured with a leaf area meter (LI-3100, Licore, Lincoln, Nebraska, USA). Mean values over the 15–20 shoots were then calculated for all the parameters. The leaf area index (LAI), defined as a dimensionless variable representing the leaf area per unit ground surface area (Jonckheere et al., 2004) was calculated by multiplying the total leaf area per shoot by the number of shoots per plant and by the number of plants per hectare, divided by 10,000 m^2. Another approach consisted in counting the total number of leaves on four replicates of 1 m canopy length, including leaves of the laterals. For each measurement time, this parameter was determined on the same plants and used to calculate the leaf area per hectare, by knowing the mean leaf surface over all the leaves measured with the leaf area meter.

2.3. Determination of the vine row volume (VRV)

The vine row volume (VRV) was determined at each developmental stage (BBCH stages 13, 16, 19, 61, 69, 75, 81) by measuring the maximal height (from the lowest leaf to the tip of the shoots) and width (in the bunch area) of the canopy. These values multiplied by 10,000 m^2 and divided by the row intervals were used to calculate the volume of the canopy per hectare. Measurements were taken at random from 10 different representative places within the experimental plots to calculate mean values.

2.4. Measurement of the deposition of tracer

Deposition and distribution of spray was measured using a fluorescent tracer (Helios SC 500, Syngenta Crop Protection AG, Basel, Switzerland) at the rate of 100 ml/ha, corresponding to 50 g fluorescent ingredient (Siegfried et al., 1990; Mantinger et al., 1994). The tracer was washed from the leaves with diethylenglycol-monoethylether and measured by photofluorimetry at an excitation wavelength of 375 nm, and measured at a wavelength of 435 nm (Fluorimeter 96, Syngenta), as described by Viret et al. (2003).

Spray deposits were assessed four times during the growing season (BBCH 14–16, 55, 61–63, 75–77). For the two first analyses, when shoots were shorter than 60 cm, 10 replicates of 10 leaves were taken randomly from the left and right side of the canopy. For the two later stages, samples were taken as described with sub-samples from the grape bunch area and from the apical part of the shoots. The position and the number of samples (20 and 40 samples, respectively, of 10 leaves) were essentially the same for the different experimental sites. Leaf areas were measured for each leaf of 20 whole shoots with a Leaf Area Meter (LI-3100, Licore, Lincoln, Nebraska, USA) to determine the average leaf surface per hectare at the time of spray application.

2.5. Dose–response curves

Dose–response curves for downy mildew were established under field conditions for the active ingredients azoxystrobin and folpet by spraying stepwise reduced dosages starting from the registered amount (150–400 g/ha for azoxystrobin and 800–1600 g active ingredient per hectare for folpet depending of the developmental growth stage of the vine). The aim of these experiments was to determine the minimum amount of active ingredient required per leaf area unit to obtain a consistent control of downy mildew after artificial inoculation with a suspension of sporangia or naturally occurring infections. Based on the leaf area to be protected on the day of application, a leaf area-dependent dosage table was established, using the average deposit of the sprayers and the dose–response curve.

2.6. Biological efficacy

The biological efficacy of season-long spraying programs adapted to the leaf area was compared to dosages adapted to the developmental stage of the vine on the experimental plots and on commercial farmer plots. Products, concentration and spraying intervals were selected according to the official recommendations (Siegfried et al., 2005). Fungal diseases were regularly assessed in untreated plots. In all treatments, the incidence of powdery and downy mildew was assessed two to three times on leaves and bunches in July and August. In each experimental plot, disease incidence (average number of infected leaves or bunches in %) and severity (average estimated diseased leaf or bunch surface in %) were assessed on four replicates of 100 randomly selected leaves, and 50 bunches according to the following scale: $0 = 0\%$, $1 \leqslant 2.5\%$, $2 \leqslant 10\%$, $3 \leqslant 25\%$, $4 \leqslant 50\%$, and $5 \geqslant 50\%$ of diseased leaf or bunch area (Müller and Schwinn, 1992).

2.7. Statistical analysis

Correlation and regression analyses were calculated with the software Excel for Windows. Normality and homoscedasticity was checked and could be improved after Log transformation of LAI and deposit values using appropriate tests available in JMP 5.1. Small violation of equal variance assumption resulted in larger prediction intervals. Sample size calculation was performed using a bootstrap re-sampling technique available in SAS v 8.2. statistical software.

3. Results

3.1. Indirect determination of the leaf area

The leaf area development clearly follows an S-curve. For similar cane-pruned training systems, with row distances from 1.7 to 2.2 m, the leaf area can vary considerably during growth (Fig. 1). The leaf area can be over 23,000 m^2/ha (LAI = 2.3), but depending on the canopy management and on the cultivar, the maximal value at the same growth stage can be as low as 12,000 m^2/ha (LAI = 1.2). Until flowering, the differences are less important and clearly related to the plant density. After flowering the canopy management directly influences the leaf area, especially the removal of lateral shoots and the trimming height. Under the climatic conditions of the Northern hemisphere, the main growing period is June, when leaf area increases generally three fold within 30 days. Observations made over several years indicate that the main growth always occurs during flowering. The S-curves can be more or less steep depending on the climatic conditions. For the same developmental stage, the LAI can be different. For example, in 2002 the LAI increased during flowering from 0.8 to 1.4, whereas in 2001, in the same plot the LAI reached only 1.0 at the same time which means a difference of 30%.

Shoot length is a simple parameter to measure and is strongly predictive of the leaf area per shoot, with a coefficient of determination $R^2 = 0.9065$ (Fig. 2). Statistical analysis was also performed for each grape cultivar and led to very consistent results. Based on these data, a 40 cm shoot has a predicted mean leaf area of 501–542 cm^2. For lengths above 100 cm the differences between plots are more important, depending on the development of lateral shoots and therefore the prediction method is less accurate (Fig. 2). Another parameter relatively easy to measure is the average VRV. Based on the same field data, the coefficient of determination between the VRV and the LAI is $R^2 = 0.8012$ (Fig. 3). This measure gives a good approximation of the LAI even if it does not consider the spaces without leaves in the canopy. The influence of the sample size on the confidence interval of the mean was analysed and indicates that with 10 shoots we can achieve a precision of 20% for the shoot length and of 30% for the LAI (Fig. 4). These values remain constant during the whole period of vegetation which means that there is no need to modify the sample size during the season to achieve a given level of precision for the mean value.

3.2. Deposit of active ingredient by the sprayers

If 1 g of an active ingredient is applied on vines with a LAI of 0.5 the average deposit on the leaves is approximately 6 ng per cm^2. At full foliage development and a LAI of 1.5, the deposit reaches approximately 3 ng per cm^2 (Fig. 5). The leaf deposit is not directly proportional to the LAI. Furthermore, for a given LAI (e.g. LAI = 1.5), the amount of active ingredient deposited on the leaf can vary by a factor of three, depending on the type of sprayer used and its calibration and setting to the canopy to be sprayed. The use of perfectly calibrated sprayers or recycling sprayers in the research institutes (analyses 2001–2002) allowed an increase in the deposit of about 50% compared with the deposit obtained with the commercial sprayers (analyses 1990–2000) used by the growers (Fig. 5).

3.3. Dose–response curves, adapted dosage and control of fungal diseases

The minimum amount required for consistently good efficacy against downy mildew was 800 ng azoxystrobin, and 3000 ng folpet per cm^2 leaf area. Based on these biological results and the knowledge of the application quality of the sprayers, a leaf area-dependent dosage table was established (Table 2). Field experiments confirmed the

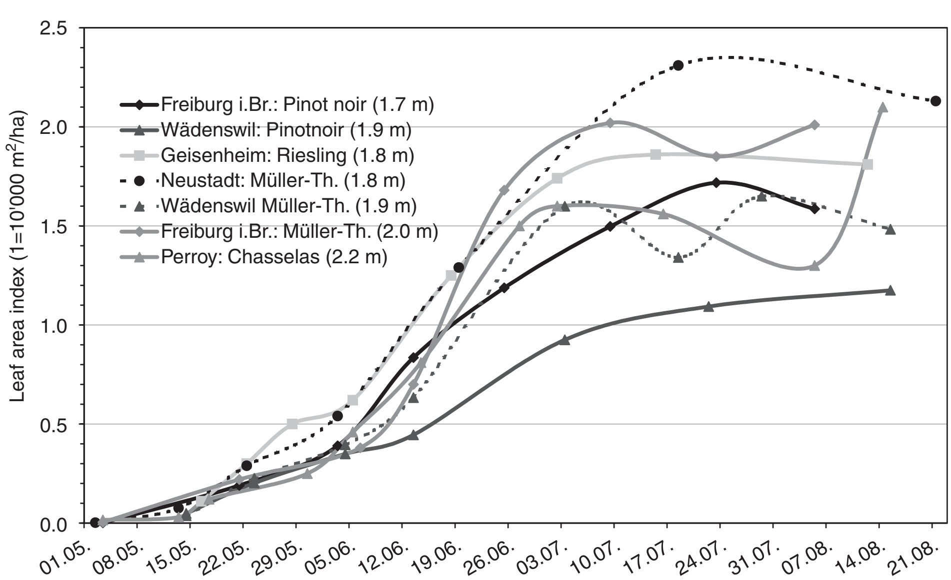

Fig. 1. Growth curves of different grapevine cultivars planted at various row intervals indicated in parenthesis. Development of the leaf area (LAI, leaf area index) in the different experimental plots in 2002.

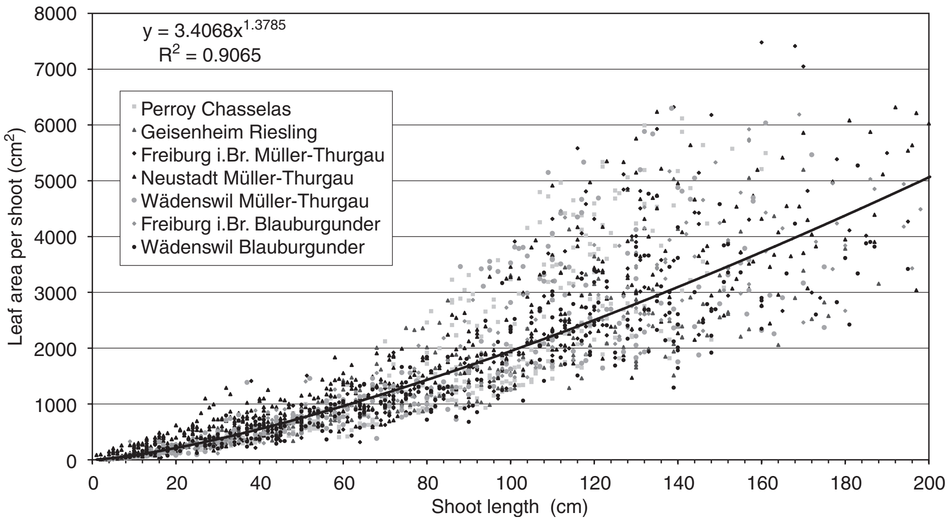

Fig. 2. Correlation between leaf area per shoot and shoot length ($N = 2100$ values) obtained on different grapevine cultivars in 2001 and 2002 (R^2 = coefficient of determination).

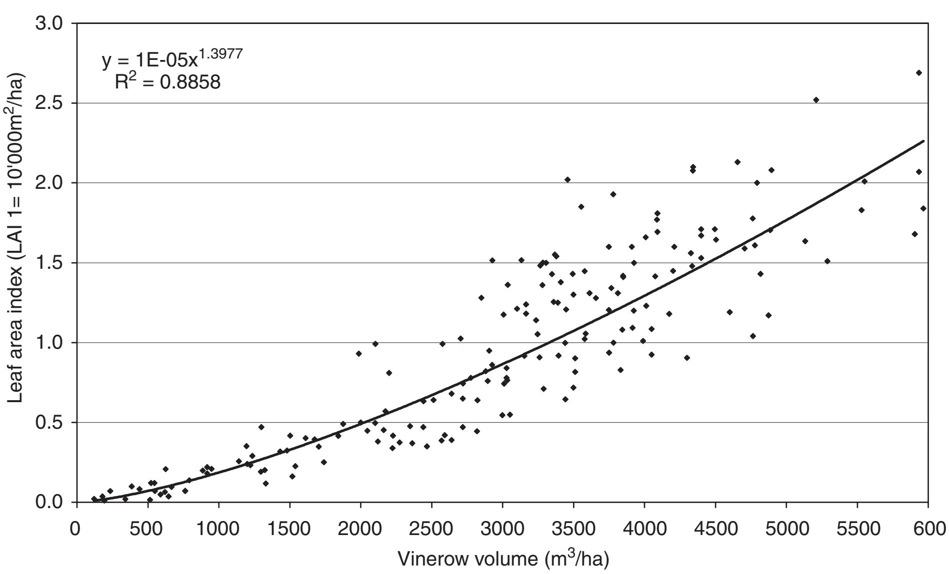

Fig. 3. Correlation between leaf area index (LAI) and vine row volume (VRV) ($N = 180$ measures) obtained on different grapevine cultivars between 2001 and 2004 (R^2 = coefficient of determination).

good efficacy against downy mildew using the adapted doses, compared with unsprayed controls and the standard dosage for folpet (Table 3). The adapted dose per hectare (mean over the season 2778 ng/cm^2 ± 524.9) clearly allowed a more constant deposit of active ingredient per leaf area unit (about 3000 ng folpet), compared to the standard dosage (mean over the season 7752 ng/cm^2 $\pm$ 1086.8), particularly when LAI was small. Similar experiments have shown the same results with azoxystrobin against both, downy and powdery mildew under different climatic conditions. The leaf area dependent dosage table was extended to other fungicides used on commercial farms and compared with the standard doses calculated by the farmers. The biological efficacy obtained under severe disease conditions for downy (Fig. 6) as well as powdery mildew (Fig. 7) showed no significant differences ($\alpha = 5\%$ level) between both dosages applied either with an axial air-blast sprayer or with a recycling sprayer.

4. Discussion

The manufacturers of spraying equipment and nozzles have made great efforts to develop spraying techniques to

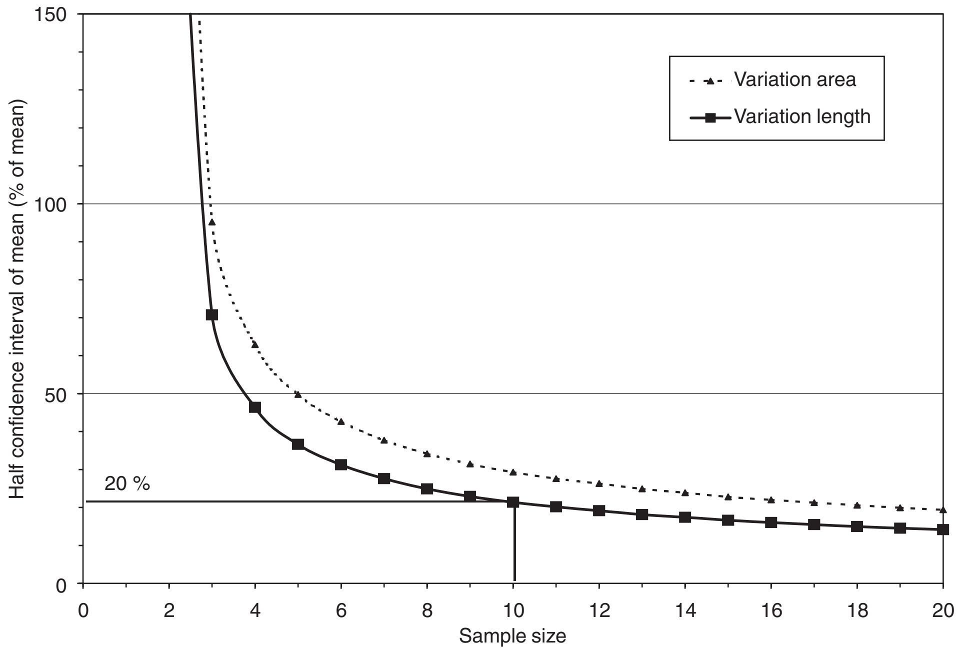

Fig. 4. Influence of sample size on confidence interval of the mean for the length of the shoots and the LAI. Bootstrap calculations performed on basis of each individual 15–20 isolated shoots sample per grape cultivar and timing.

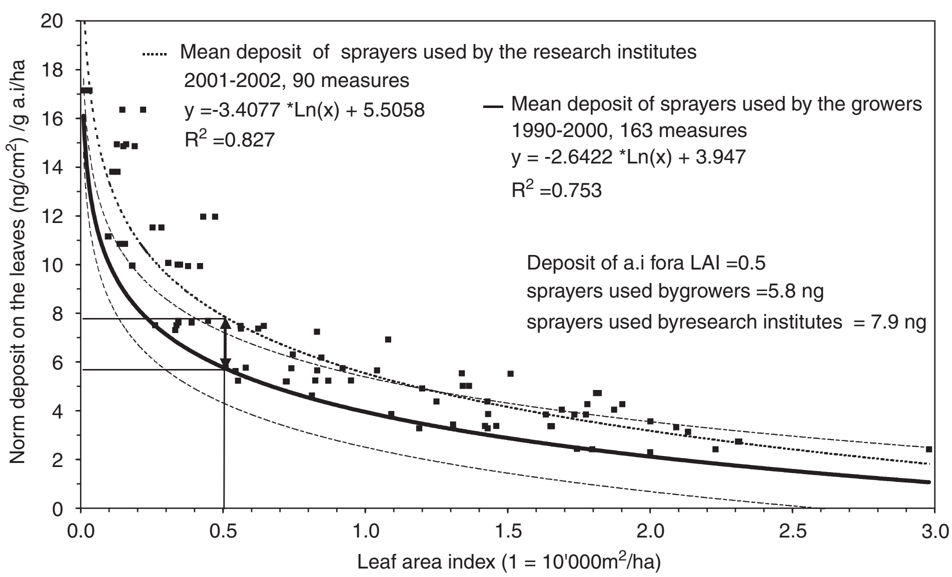

Fig. 5. Mean leaf deposit curves and 80% confidence intervals of different commercial sprayers used by the growers ($N = 163$ measures with axial, reverse-axial, tunnel and pneumatic sprayers, 1990–2000) and of sprayers used by the research institutes ($N = 90$ measures with tunnel and axial sprayers, 2001–2002), related to the leaf area index. Each point represents the mean deposit value analysed on 10–40 leaves.

reduce the unnecessary contamination of the environment (Ripke and Warnecke-Busch, 1999; Matthews and Thomas, 2000). These include recycling sprayers (Siegfried et al., 1993), drift reducing nozzles (Lund, 2000; Pigott and Matthews, 1999) and sensor techniques (Koch and Weisser, 2000). At the same time, the registered and recommended product dosages against a grapevine disease spectrum may vary from country to country (Rüegg et al., 2001). As concentration or hectare based dose recommendations have an intrinsic risk of dose errors leading to negative impacts on efficacy or resistance management, application specialists from academia and industry generally agree that the dose of pesticides should be linked with the leaf area present on the day of application (Walklate et al., 2003). An accurate and easy determination of the leaf area is the key element. New technology, such as LIDAR (light detection and ranging), has enabled characterization of the leaf canopy in fruit orchards to optimize pesticide

Table 2
Dosage adapted to the leaf area considering the average deposit capacity of air-blast sprayers and the dose-efficacy values for azoxystrobin and folpet

Vine row volume (VRV) m^3/ha	Leaf area index $1 = 10{,}000\,m^2$/ha	Average normalized deposit of air-blast sprayer[a] (ng/cm^2)(g/ha)	Adapted dose for azoxystrobin[b] (800 ng/cm^2 for a good efficacy) ml a.i./ha	Adapted dose for Quadris[c] (250 ml a.i./l) l/ha	Adapted dose for folpet[b] (3000 ng/cm^2 for a good efficacy) mg a.i./ha	Adapted dose for Folpet[c] (80% a.i./kg) kg/ha	Percentage of adaptation (100% for a VRV of 4500 m^3/ha) %	Recommended water volume for air-blast sprayers[d] l/ha
400	0.04	12.3	85	0.34	317.1	0.40	21	
600	0.08	10.6	98	0.39	367.9	0.46	25	
800	0.12	9.5	109	0.44	410.5	0.51	27	
1000	0.17	8.6	121	0.48	453.5	0.57	30	50–100
1200	0.23	7.9	132	0.53	493.7	0.62	33	
1400	0.28	7.3	143	0.57	534.2	0.67	36	
1600	0.35	6.7	154	0.62	582.1	0.73	39	
1800	0.42	6.3	166	0.66	619.0	0.77	42	
2000	0.49	5.8	178	0.71	672.4	0.84	45	100–200
2200	0.56	5.5	190	0.76	709.1	0.89	48	
2400	0.64	5.1	203	0.81	764.7	0.96	51	
2600	0.73	4.8	217	0.87	812.5	1.02	54	
2800	0.81	4.5	231	0.92	866.7	1.08	58	
3000	0.90	4.2	246	0.98	928.6	1.16	62	200–300
3200	0.99	4.0	262	1.05	975.0	1.22	66	
3400	1.09	3.7	279	1.12	1054.1	1.32	70	
3600	1.19	3.5	297	1.19	1114.3	1.39	74	
3800	1.29	3.3	317	1.27	1181.8	1.48	79	
4000	1.39	3.1	338	1.35	1258.1	1.57	85	300–400
4200	1.50	2.9	361	1.44	1344.8	1.68	90	
4400	1.61	2.7	386	1.54	1444.4	1.81	97	
4600	1.72	2.5	413	1.65	1560.0	1.95	103	
4800	1.83	2.3	443	1.77	1695.7	2.12	111	
5000	1.95	2.2	476	1.90	1772.7	2.22	119	400–500
5200	2.07	2.0	513	2.05	1950.0	2.44	128	
5400	2.19	1.9	554	2.22	2052.6	2.57	139	
5600	2.32	1.7	600	2.40	2294.1	2.87	150	
5800	2.44	1.6	653	2.61	2437.5	3.05	163	
6000	2.57	1.5	714	2.86	2600.0	3.25	179	500–600

The proposed adaptation includes a security margin of 30%.

[a]Based on deposit curves (Fig. 5).

[b]Based on dose–response experiments under filed conditions, the values include a security margin of 30%.

[c]Registered amount of Quadris 1.6 l/ha and of Folpet 2 kg/ha.

[d]Based on long time experiments, these recommended water volumes allow a regular deposit and a good distribution of the spray broth on the target.

Table 3
Biological efficacy of the standard and adapted dose for folpet (80% active ingredient) against downy mildew under filed conditions (experimental plot of Wädenswil, 2002, cv. Müller-Thurgau, sprayed with an axial fan sprayer, spray broth volume of 200–400 l/ha)

Wädenswil 2002	29 May	6 June	19 June	1 July	18 July	29 July
Vine row volume VRV (m^3/ha)	1400	2000	2800	3700	3700	3800
LAI (1 = 10,000 m^2/ha)	0.28	0.40	0.75	1.60	1.30	1.70
Folpet, standard dose (g a.i./ha)	800	1040	1200	1600	1600	1600
Folpet, adapted dose (g a.i./ha)	300	400	432	544	544	544
Norm deposit for air-blast sprayer (ng/cm^2)/(g/ha)	11.2	8.8	5.4	4.7	4.7	4.3
Folpet, standard dose (ng/cm^2)/ha	8960	9152	6480	7520	7520	6880
Folpet, adapted dose (ng/cm^2)/ha	3360	3520	2333	2557	2557	2339
Downy mildew unsprayed control, leaves (%)	18	—	58	—	91	100
Downy mildew unsprayed control, grapes (%)	—	—	—	—	95	100
Efficacy standard dose on leaves (%)	100	—	100	—	94	98
Efficacy adapted dose on leaves (%)	100	—	100	—	97	94

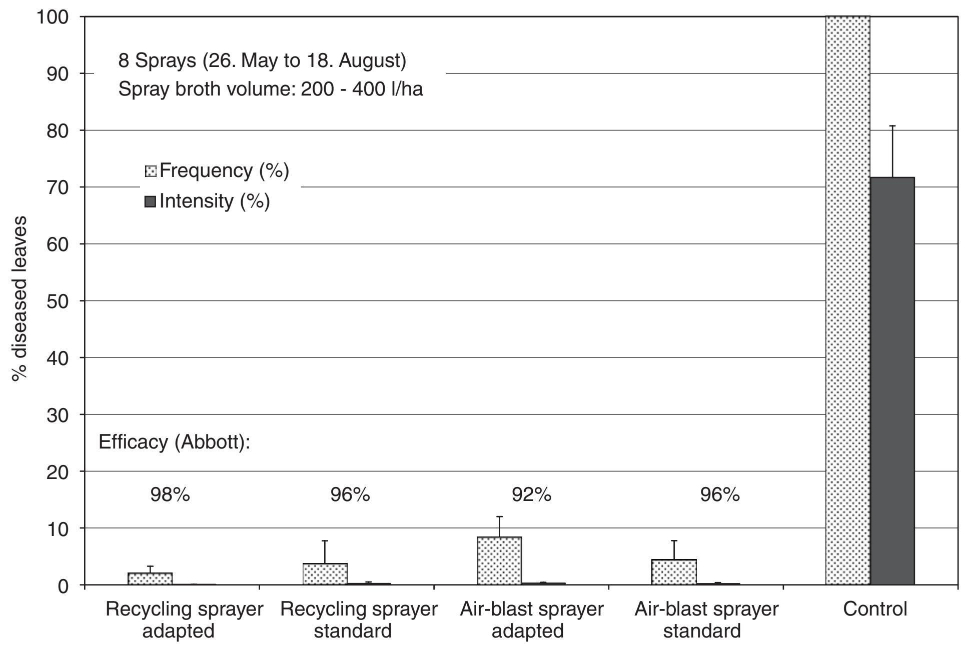

Fig. 6. Biological efficacy of adapted and standard dose for a spray program including different active ingredients against downy mildew in 2004 (field trial Wädenswil, cv. Müller-Thurgau), applied with a recycling and an air-blast sprayer. Mean disease frequency and severity with standard deviation (bars) calculated on four replicates of 100 leaves, efficacy according to Abbott.

treatments (Sanz et al., 2005; Walklate et al., 2002). The tree row volume concept (TRV) (Siegfried et al., 1995; Rüegg and Viret, 1999; Rüegg et al., 1999) has been the basis for the registration of plant protection products in fruit orchards in Switzerland. However, in viticulture, this approach has not been adopted yet mainly due to the more pronounced diversity of growing systems and crop husbandry management, but also due to the diversity of spraying equipment being used.

The development of the leaf area of the grapevine follows an S-curve which can show great variation depending on the climatic conditions, grape varieties, plant densities and pruning system. The plant density and the height of the canopy are the most important factors for the development of the leaf area. The shoot growth and the related leaf area can considerably increase within a short period of time, justifying the adaptation of the dose to the leaf area. Both methods to estimate the leaf area, by measuring the shoot length or VRV, based on the assumption that each row is a rectangular box of foliage, consider these major influencing factors. The data obtained on the cultivars Müller-Thurgau, Chasselas, Pinot Noir, and Riesling from both methods were consistent. The coefficient of determination between the leaf area and the VRV or the shoot length could be slightly improved by using the log-transformed values. First results obtained on the cultivars Merlot, Chardonnay, Cabernet Sauvignon and Gamay in Spain, Italy and Switzerland are comparable. From a practical point of view

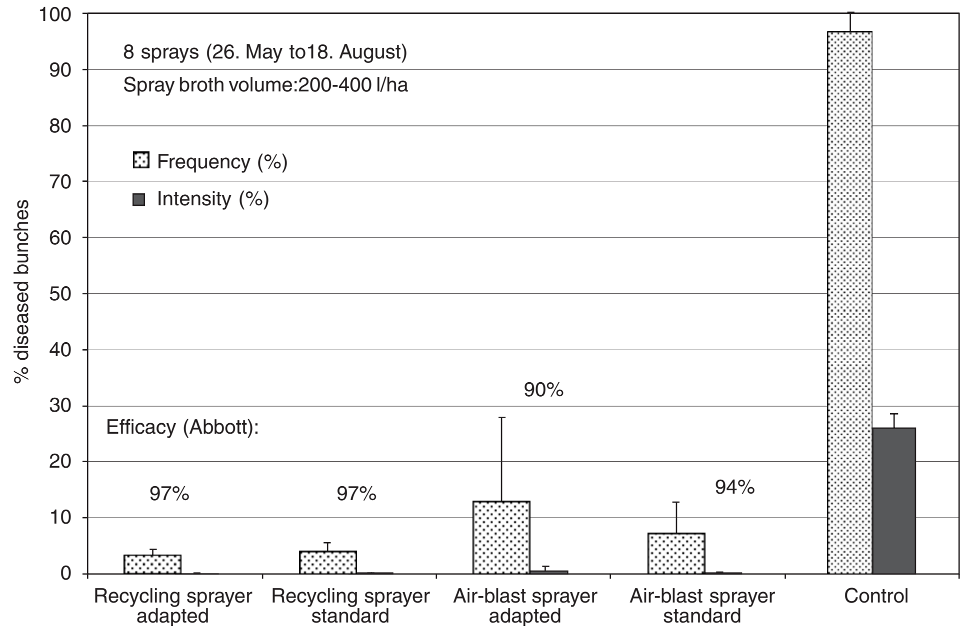

Fig. 7. Biological efficacy of adapted and standard doses for a spray program including different active ingredients against powdery mildew in 2004 (field trial Wädenswil, cv. Müller-Thurgau), applied with a recycling and an air-blast sprayer. Mean disease frequency and severity with standard deviation (bars) calculated on four replicates of 50 bunches, efficacy according to Abbott.

the measurement of the VRV by the simple equation (height $\times$ width $\times$ 10,000)/row distance is easier to perform for the growers than the shoot length method (Viret et al., 2005). In spring the shoot length can be variable from shoot to shoot and from plant to plant. Therefore, at least 10 shoots should be measured for an accurate average value, which is not the case to determine the VRV. The measurement of the width and height of the canopy on three to five vines can be rapidly achieved with enough precision.

Spray deposit is a key element for successful disease control. The LAI-dependent deposit curves obtained with different kinds of sprayers indicated that the normalized deposit per leaf area unit decreases with increasing LAI, if the applied dose is kept constant (1 g/ha). However, for a given LAI the difference between the best and the lowest deposit for sprayers used in practice can be high. The biological efficacy can be insufficient for sprayers that produce the lowest deposits. As all the sprayers were properly calibrated (Raisigl and Felber, 1991), the mean deposit obtained with these sprayers was clearly higher than the mean deposit from commercial sprayers, confirming that proper and periodical calibration is a prerequisite for a good application quality. As far as we know, this is the first report on LAI-dependent deposit curves under field conditions with different sprayer types. The proposed dosage table is based on the average sprayers used in practice with an additional safety margin of 30%. Viret et al. (2003) have reported that the equal distribution of the active ingredient on both leaf surfaces is as important for a good efficacy, as the amount of product deposited. In this context, the application of fungicides by spraying only each second or third grapevine row, to rationalise the spraying process, is counterproductive in order to reach this goal. For such cases, the LAI-adapted dosage is not suited.

Water is only the carrier of the pesticides to the leaf surface. The LAI-adapted dosage allows a precise calculation of the amount of product depending on the leaf surface per hectare. The water volume can vary depending on the sprayer characteristics (Pergher and Gubiani, 1995). However, extreme reduction of the water volume can lead to poor distribution of active ingredients on the leaf surface, as well as too much water leads to run-off. Field experiments have shown that there is an optimum volume to provide thorough coverage and disease control, as reported for pomefruits (Mantinger et al., 1994).

Adapting the dosage to the leaf area as shown in this paper provides a practical system for the standardization of field experiments for the registration process. It also enables vine growers to calculate precisely the amount of product to use per hectare. Although, the unit canopy row method developed in Australia (Furness et al., 1998) is basically similar, it is not based on the effective leaf area, does not consider the deposit of the sprayers and is not adapted to the practical conditions of the European vineyards, where variation in plant density and small, often irregular plots renders the calculation of rates per 100 m row units nearly impossible.

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