ISSN 2083-1587; e-ISSN 2449-5999
2024,Vol. 28,No.1, pp. 367-377
Agricultural Engineering
www.wir.ptir.org

DOI: 10.2478/agriceng-2024-0023

RECENT DEVELOPMENTS IN THE EVALUATION OF THE PERFORMANCE OF VINEYARD SPRAYERS

Jean-Paul Douzals[a]*, Olivier Naud[b], Sebastien Codis[c], Adrien Verges[d], Florence Verpont[e]

[a] UMR ITAP INRAE, Université de Montpellier, UMT Ecotech, 361 Rue JF Breton, Montpellier, France, jean-paul.douzals@inrae.fr, ORCID 0000-0002-0416-0322,
[b] UMR ITAP INRAE, Université de Montpellier, UMT Ecotech, 361 Rue JF Breton, Montpellier, France, olivier.naud@inrae.fr, ORCID 0000-0001-5663-5062,
[c] IFV, UMT Ecotech, 361 Rue JF Breton, Montpellier, France, sebastien.codis@vigneetvin.com, ORCID 0000-0002-3095-0328,
[d] IFV, UMT Ecotech, 361 Rue JF Breton, Montpellier, France, adrien.verges@vigneetvin.com, ORCID 0000-0002-1956-2201,
[e] CTIFL, UMT Ecotech, 28 route des Nébouts, Prigonrieux, France, florence.verpont@ctifl.fr, ORCID 0009-0004-4271-4623,

Corresponding author: e-mail: jean-paul.douzals@inrae.fr

ARTICLE INFO

Article history:
Received: May 2024
Received in the revised form: November 2024
Accepted: December 2024

Keywords:
Spray deposition,
3D crops,
Spray drift

ABSTRACT

Vines are perennial crops that appear sensitive to various diseases and insects with a subsequent number of spray applications per year. In general, biological efficacy is strongly linked to the spray quantity and quality, assuming that non-intercepted droplets may lead to ground or atmospheric losses. This paper corresponds to a *synthetic* review focusing on need for generic methodology to assess vineyard sprayer deposition performance. Indeed, the deposition of droplets in a 3D canopy is a complex phenomenon that encompasses a wide range of variability that limits the capability for evaluating and for comparing field tests. Different levels of crop variability were identified among the cultivar, the development stage and the training strategy leading to a highly variable leaf area index over time. Other sources of variability depend on the sprayer technology where the air assistance and droplet emitters play a key role. Assuming the difficulties in the comparison of sprayers directly through field tests, the rationale for a fair and replicable comparison of sprayer deposition performance was developed by the joint unit UMT Ecotech between INRAE and associated technical institutes for vines (IFV) and fruit crops (CTIFL). An original methodology to assess sprayer deposition capability was developed based on an artificial vineyard whereas the potential spray drift of the complete sprayer is evaluated using an artificial wind generator. These test benches are now used in a purpose of official classification by French authorities.

Introduction

Spraying is the main method used to apply plant protection products on vineyards and orchards, once the IPM strategy failed to propose alternative solutions. Compared with other agricultural production sectors, viticulture and horticulture show a variety of sprayer designs adapted to either a wide range of – or specific – growing conditions (vegetation height and depth, spacing, trellising, pruning, plot size, etc.). The European Green Deal and the Farm to Fork strategy led to reconsider all the factors that may help to reduce the quantities and the impact of plant protection products. When looking at all existing solutions to satisfy these two previous requirements, the influence of spraying technology performance was paradoxically under-considered. Indeed, for a long time, the specifications for equipment design were limited to improving productivity and satisfying operator safety requirements, with a limited consideration of agronomical nor environmental considerations.

The main function of a 3D crop sprayer is then to produce droplets and enable them to be transported and deposited on targets (leaves, bunches). In practice, this process is quite complex, involving numerous and sometimes unpredictable parameters linked to the equipment (general design, nozzles or diffusers, air assistance), terrain conditions (slope, gradient, forward speed), the crop (inter-row width, distance to target, vigor), weather conditions, the physico-chemical properties of the tank mix (viscosity, surface tension), etc.

Very few studies focused on the evaluation of the mass balance of a spray application (Jensen and Olesen, 2014; Balsari et al., 2005; Salyani et al., 2007; Fritz et al., 2018) however, some experimental works showed the high variability of the deposition in some key compartments (Fig. 1).

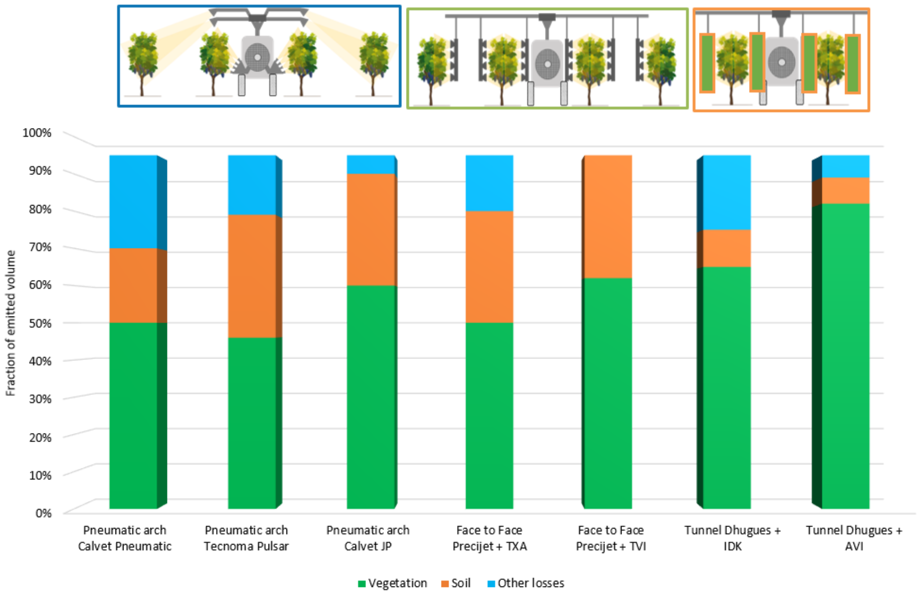

Figure 1. Estimated mass balance of an application achieved with several vineyard sprayers (source UMT Ecotech, Montpellier)

The seek for a better efficiency of sprayers leads to two main questions: I) what are the major determining factors of the spray efficiency and II) how to evaluate these major determining factors?

Major determining factors of spray application efficiency

In the absence of more precise specifications, the physical efficiency of a spray application can be defined as i) the maximization and the homogeneity of spray deposition on target and ii) the minimization of both ground losses in the field and air losses contributing to spray drift (beyond the field edge).

Table 1.
Variability of vine canopy indicators during the growing season. (Djouhri, 2022)

Growth stage (BBCH)	Early stage (BBCH 19)	Late stage (BBCH 57)
Canopy Height, (m)	1.43	2.0
Minimum leaf wall height, (m)	0.5	0.4
LAI field scale, (m^2·ha^{-1})	1	3
LAI row scale, (m^2·ha^{-1})	7.8	10.7
Row width, (m)	0.32	0.70

Evaluation of spray deposits in vines as a function of the density of leaves

When measuring spray deposits in a vineyard, the quantities collected on the foliage are directly linked to the number of leaves capable of intercepting the spray droplets. The quantities collected are then correlated with the Leaf Wall Area (LWA) index (given in m^2 per ha), although there are differences depending on the type of sprayer, as illustrated in the following Fig. 2 (Grella et al., 2020).

Note that LWA is inversely proportional to inter-row width; so, for vegetation of the same vigor level, LWA values for narrow vines are consequently higher.

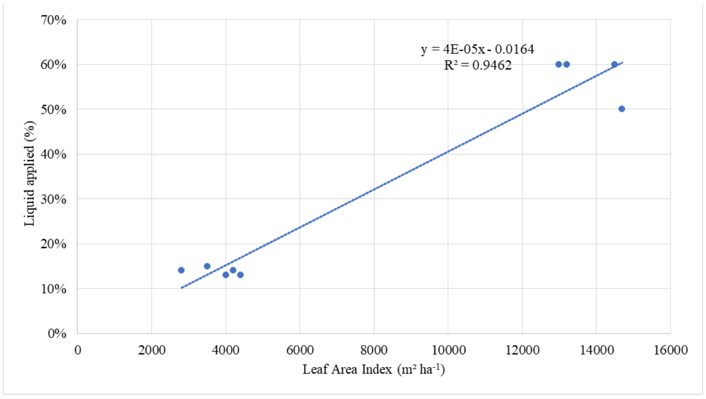

Figure 2. Evolution of canopy deposition according to Leaf Wall Area (m^2·ha^{-1}). After Grella et al., 2022

Normalized spray deposits per surface unit of leaf

Since the leaf surface is highly variable in time and space, it is common to normalize the spray deposition quantity per unit of leaf surface in µg of dye tracer per cm² (Fig. 3).

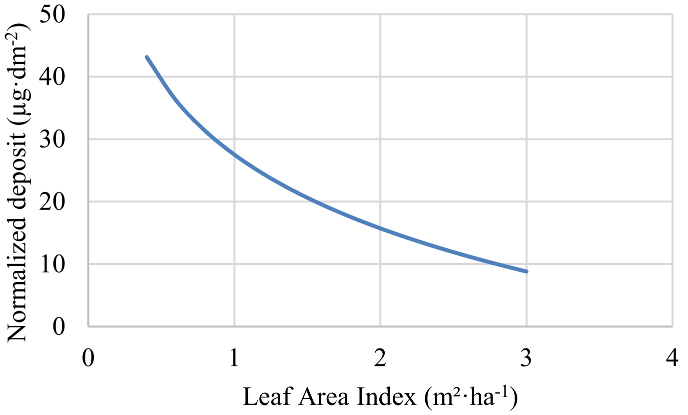

Figure 3. Example of normalized deposits in µg·dm⁻² as a function of LAI for vine, 90 tests with recent sprayers (2001-02), Siegfried et al. (2005) cited by Pergher and Petris, 2007

As a consequence, figure 2 shows that a similar volume rate (or dye mass per ha) applied to a vine canopy leads to spray deposits varying in a range of one (at early stage) to five (at a later stage) but in the same time, the normalized deposition (Fig. 3) is four time higher at early stage than as for late stage. This is a kind of paradox. The vegetation stage through for example the BBCH (from German Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie) scale (Zadock, 1974) and the associated total leaf area are to be considered for the evaluation of a sprayer performance.

Minimizing ground and air losses

Ground losses in the field have two possible causes: I) a bad orientation of nozzles or diffusers and II) a droplet size greater than 400 µm, which can lead to a leaf runoff of the sprayed liquid.

Alternatively, spray drift losses correspond to an aerial transport of droplets by the wind, during the spray application. This phenomenon leads to the contamination of the environment outside the treated plot. These two types of losses are illustrated in the Fig. 4 below for a conventional airblast sprayer compared to crossflow sprayer (Grella et al., 2020):

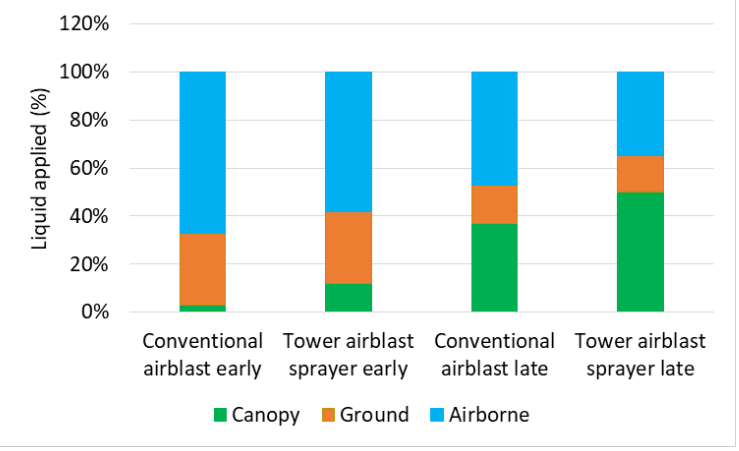

Figure 4. Evolution of losses (sol – air) from two vineyard sprayers. After Grella et al., 2020

Means to evaluate sprayers performance and related indicators

Solution 1: Evaluation of sprayers through field tests

Field measurements are the most common means of carrying out performance measurements, even though they are time consuming and laborious and results may depend on meteorological conditions. In the case of Grella et al., (2020), a gantry was designed around a vine row in order to assess each and every compartment in a perspective of a mass balance assessment (Fig. 5).

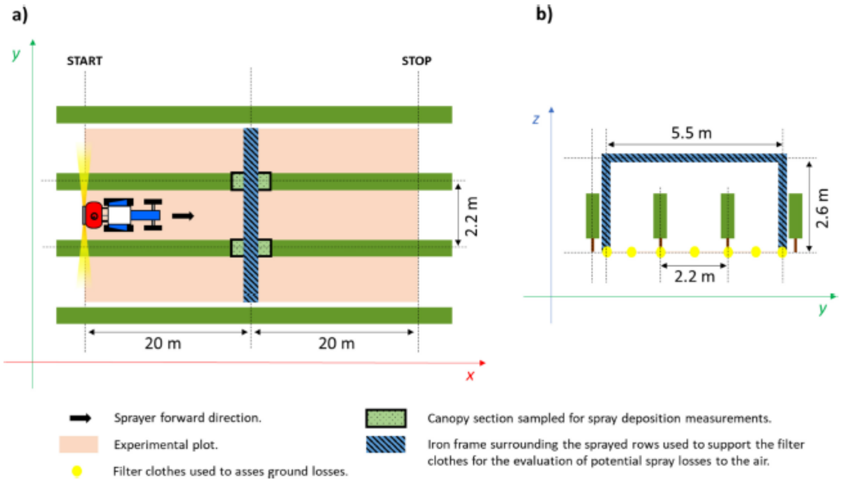

Figure 5. Experimental setup for a vine sprayer mass balance assessment. After Grella et al., 2020

Similarly, an international standard, ISO 22866 (2005), describes the test procedure and conditions to validate spray drift (aerial or sedimentary) measurement in the field. The constraints imposed by wind velocity and direction make these tests highly unpredictable, and require quite a large number of tests to stabilize values under variable wind conditions.

Solution 2: Measurements with artificial or semi controlled conditions

An earlier study used a “cage” of PVC wires to assess aerial losses around four rows of artificial vines (Gil et al., 2007) made up of windbreaks (Fig. 6).

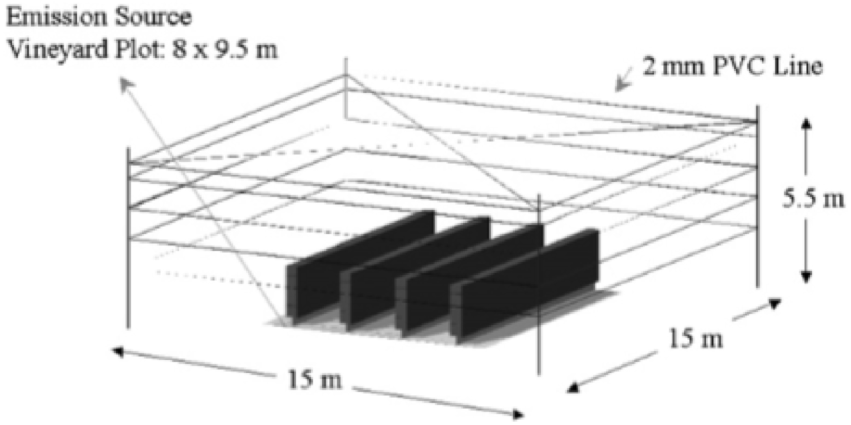

Figure 6. Evaluation of airborne losses. After Gil et al., (2007)

One of UMT Ecotech's flagship projects has been to develop and validate a methodology for assessing the performance of vineyard sprayers through quantitative deposition assessment. This project has now resulted in a voluntary classification of vineyard known as Performance Pulvé (http://www.performancepulve.fr). A similar classification is now being developed for sprayers used in orchard and horticulture.

The structure of the artificial vegetation, named Evaspray viti, is composed of 10 m long rows including nets surrounding the central part with plastic leaves (Fig. 7). The test bench may reproduce up to three different growth stages mimicking early, intermediate and late development stages of a vine, and deposition similarities with a real vine was verified (Cheraiet et al., 2022; Cheraiet et al., 2024).

A food dye (Tartrazine, 5 g·L^{-1}) is sprayed so that the leaf deposition may be quantified in the laboratory after sampling in up to nine canopy compartments (3 heights x 3 depths) at late stage. A global evaluation of a sprayer is conducted taking into account the score obtained at the three growth stages. For each growth stage, the score includes the average deposition (X-axis Fig. 8) and the coefficient of variation (CoV) (Y axis – Fig. 8) between canopy compartments.

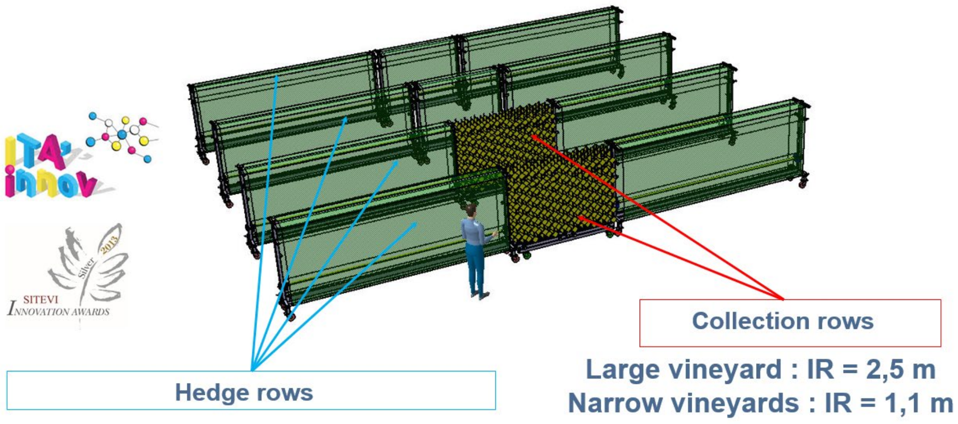

Figure 7. Evaspray viti test bench used for the evaluation of deposition performance of vineyard sprayers, Source UMT Ecotech, Montpellier

After more than ten years and 150 individual tests, a voluntary classification of vineyard sprayers was drawn as illustrated by Fig. 8.

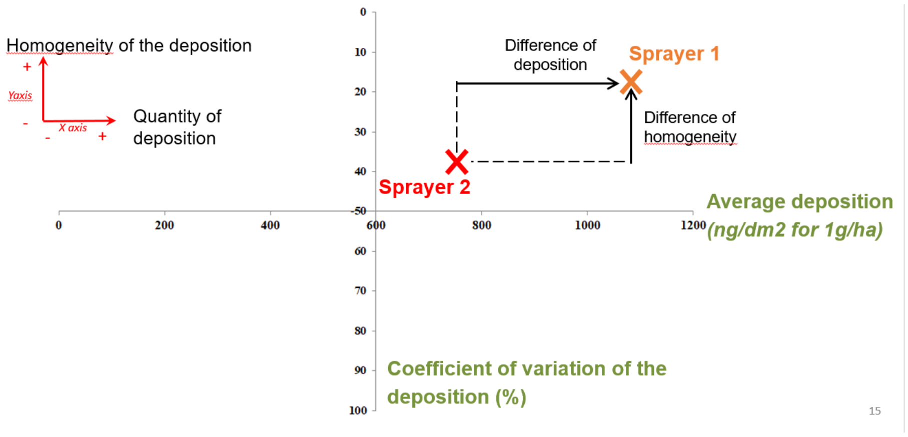

Figure 8. Basis for the comparison of the performance of deposition of vineyard sprayers
Source UMT Ecotech, Montpellie.

If it is possible to carry out spray drift measurements under controlled conditions using wind tunnels with individual nozzles, wind tunnels are generally not adapted to test a complete sprayer. UMT Ecotech's second emblematic project was to develop a wind generator (named EoleDrift – Fig. 9) to generate semi-controlled wind conditions for routine measurement of potential spray drift issued from vine and orchard sprayers (Fig. 9). In this case airborne spray drift is evaluated using PVC strings of 2mm diameter and 5m long placed every 0.5m from 0.5m up to 6m from the ground. Compared to field tests, this protocol appears to involve the major advantage of a high reproducibility. Petri dishes and mannequins were also used, respectively, for ground deposition (sedimentation drift) and bystanders' exposure at different distances from the last row.

Figure 9. Potential spray drift measurement combining artificial wind and an artificial vineyard Source: UMT Ecotech, Montpellier

Solution 3: Evaluation of sprayer performance using modelling

The evaluation of the spraying performance in viticulture has long been absent from modelling work, which has focused more on row crops or orchards (Chahine et al., 2011; Holterman et al., 1997; Teske et al., 2003). Very recently, an innovative model was developed (named ADDI Spray Drift; ADDI stands for Airborne Drift Deposition Interception). This model, based on a random walk approach, integrated the entire process from Ii) the description of emission conditions and the transport of droplets: droplet size distribution, droplet direction and velocity and the evaporation process over time of flight, II) the interception by the vegetation and the eventual deposition on the ground inside and outside of the field and III) the potential aerial interception by bystanders. It considered weather conditions (like temperature and relative humidity), wind speed and direction (Djouhri et al., 2023) (Fig. 10).

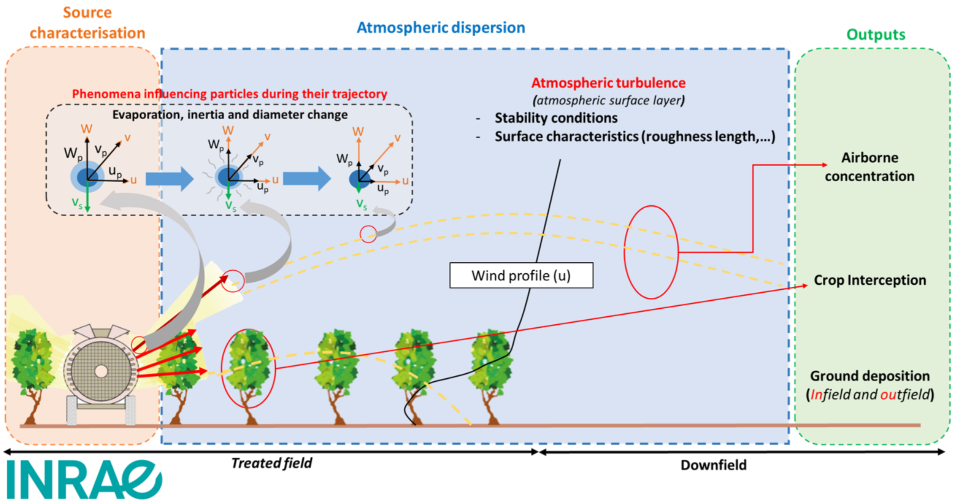

Figure10. Basis of ADDI-Spray drift modelling. After Djouhri et al. (2023)

The preliminary results showed the capability of the modelling to discriminate between contrasted sprayer design and the influence of the design on the spray application performance (Fig. 11). The global distribution of the spray mix in the different compartments was compared for three types of sprayers and the influence of standard or drift reducing nozzles, when applicable. The results globally reflected what can be observed after field tests.

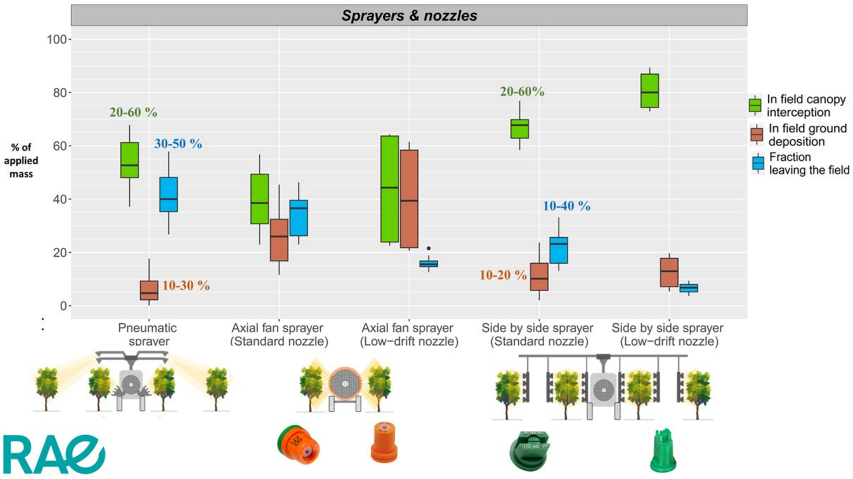

Figure 11. Spray deposition into different compartments simulated for three contrasted sprayer designs. After Djouhri et al. (2023)

Conclusion

The spray application itself plays a major role in application performance, with many sources of variability. Recent studies on the evaluation of sprayers performance carried out by UMT Ecotech has focused on the development of equipment and test benches to improve target deposition and mitigate spray drift, the first stage in a more comprehensive evaluation of mass balance. Recent developments in modelling would help to reduce the total number of tests required but also to consider the influence of more numerous variables in a perspective of a better information to the spray operator and automatic settings options for sprayers in order to more easily adapt to changing conditions (crop, weather, products, etc.)

Author Contributions: Original draft preparation, JP.D.; formal analysis & conceptualization, O.N., S.C., A.V., F.V.

Conflicts of Interest: The authors declare no conflict of interest.

Funding: This research received no external funding.

Acknowledgments: Authors would like to acknowledge all INRAE, IFV and CTIFL staff that have contributed to above mentioned research

References

Balsari, P., Marucco, P., Tamagnone, M. (2005). A system to assess the mass balance of spray applied to tree crops. *Transactions of the ASABE*. Vol. *48*(5), 1689-1694.

Chahine, A. (2011). Modelling of aerial dispersion of pesticides from local to regional scales, influence of infrastructures and quantification of levels of exposure. PhD Thesis University of Montpellier (in French) 184p. Link available on Dec 9th 2024: https://theses.fr/2011NSAM0037?domaine=theses

Cheraiet, A., Naud, O., Carra, M., et al. (2022). Evaluation of the distribution of spray deposits within a vine canopy from measurements on artificial targets and real leaves. *Oeno One.* Vol. *56*(4).

Cheraiet, A., Codis, S., Lienard, et al. (2024). EvaSprayViti: a flexible test bench for comparative assessment of the 3D deposition efficiency of vineyard sprayers at multiple growth stages *Biosystems Engineering*. Vol. *241*(3), 1-14. https://dx.doi.org/10.1016/j.biosystemseng.2024.03.008.

Djouhri, M. 2022. Modelling of spray distribution and spray drift of pesticides during a spray application and their contribution to bystander exposure: case of viticulture. PhD thesis University of Montpellier (in French), 189p. Link available on Dec 9th, 2024: https://ged.scdi-montpellier.fr/florabium45/jsp/nnt.jsp?nnt=2022UMONG073.

Djouhri, M., Loubet, B., Bedos, C., et al. (2023). ADDI-Spraydrift: A comprehensive model of pesticide spray drift with an assessment in vineyards, *Biosystems Engineering*. Vol. 231, 57-77. https://doi.org/10.1016/j.biosystemseng.2023.05.008.

Fritz, B.K., Hoffmann, W.C., Martin, D.E., Butts, B.K. (2018). Mass Balance and Swath Displacement Evaluations from Agricultural Application Field Trials. In Pesticide Formulation and Delivery Systems: 38th Symposium on Innovative Application, Formulation and Adjuvant Technologies. New Orleans, LA. ASTM Int Comm E35 Pesticides Antimicrobials & Alternat Control Agents, volume 1610, 11-23. https://doi.org/10.1520/STP161020170204.

Gil, Y., Sinfort, C., Brunet, Y. (2007). Atmospheric loss of pesticides above an artificial vineyard during air-assisted spraying. *Atmospheric Environment.* Volume 41, 2945-2957. https://doi.org/10.1016/ j.atmosenv.2006.12.019.

Grella, M., Marucco, P., Oggero, G., Manzone, M., (2022). Environmental Evaluation of Vineyard Airblast Sprayers Through a Comprehensive Spray Mass-Balance Approach. In: Biocca, M., Cavallo, E., Cecchini, M., Failla, S., Romano, E. (eds) Safety, Health and Welfare in Agriculture and Agro-food Systems. SHWA 2020. Lecture Notes in Civil Engineering, 252. Springer, Cham. https://doi.org/10.1007/978-3-030-98092-4_39.

Holterman, H. J., Van de Zande, J. C., Huijsmans, J. F. M., Wenneker, M. (2017). An empirical model based on phenological growth stage for predicting pesticide spray drift in pome fruit orchards. *Biosystems Engineering*. Vol. 154, 46–61. https://doi.org/10.1016/j.biosystemseng.2016.08.016

Jensen, P.K. and Olesen M.H. (2014). Spray mass balance in pesticide application: A review. *Crop Protection*, volume 61, 23-31. https://doi.org/10.1016/j.cropro.2014.03.006

Pergher, G. & Petris, R. (2007). Pesticide Dose Adjustment in Vineyard Spraying and Potential for Dose Reduction. *Agricultural Engineering International*: the CIGR Ejournal. X.

Salyani, M., Farooq, M., Sweeb, RD. (2007). Spray deposition and mass balance in citrus orchard applications. *Transactions of the ASABE*, *50*(6), 1963-1969.

Teske, M. E., Thistle, H. M., & Ice, G. G. (2003). Technical Advances In Modeling Aerially Applied Sprays. *Transactions of the ASABE*, *46*(4), 985–996. https://doi.org/10.13031/2013.13955

Zadoks, J.C. (1974). A decimal code for the growth stages of cereals, *Weed Research*, volume 14, 415–421.

NAJNOWSZE OSIĄGNIĘCIA W OCENIE WYDAJNOŚCI OPRYSKIWACZY W WINNICACH

Streszczenie. Winorośle to uprawy wieloletnie podatne na różne choroby i szkodniki, co wymaga wielokrotnych oprysków w ciągu roku. Ogólnie skuteczność biologiczna jest silnie powiązana z ilością i jakością oprysku, przy założeniu, że krople, które nie osiadają na liściach, mogą powodować straty do gleby lub atmosfery. Artykuł przedstawia przegląd i potrzebę stworzenia uniwersalnej metodologii oceny efektywności deponowania oprysku przez opryskiwacze w winnicach. Depozycja kropli w trójwymiarowej strukturze roślinnej jest złożonym procesem, w którym występuje wiele zmiennych utrudniających ocenę i porównanie testów polowych. Różne poziomy zmienności upraw zostały zidentyfikowane w zależności od odmiany winorośli, fazy jej rozwoju oraz systemu prowadzenia, co prowadzi do dużej zmienności indeksu powierzchni liści w czasie. Inne źródła zmienności wynikają z technologii opryskiwaczy, gdzie kluczową rolę odgrywają wspomaganie powietrzem i emitery kropli. Biorąc pod uwagę trudności w bezpośrednim porównywaniu opryskiwaczy za pomocą testów polowych, opracowano uzasadnienie dla sprawiedliwego i powtarzalnego porównania wydajności deponowania oprysku. Jednostka badawcza UMT Ecotech we współpracy z INRAE oraz technicznymi instytutami winiarskimi (IFV) i sadowniczymi (CTIFL) opracowała oryginalną metodologię oceny zdolności opryskiwaczy do deponowania. Została ona opracowana z wykorzystaniem sztucznej winnicy, podczas gdy potencjalny dryf oprysku całego urządzenia oceniano za pomocą sztucznego generatora wiatru. Obecnie te stanowiska testowe są wykorzystywane w celu oficjalnej klasyfikacji przez francuskie władze.

Słowa kluczowe: osadzanie oprysku, uprawy 3D, dryf oprysku