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# Spray penetration within vine canopies at different growth stages

By A DA SILVA, C SINFORT, B BONICELLI

*Unité Mixte de Recherche « ITAP », ENSA.M-Cemagref, BP 5095, 34 090 Montpellier, F*

M VOLTZ

*Unité Mixte de Recherches Sol et Environnement INRA-ENSA.M, 2 place Viala, 34060-Montpellier-Cedex 1, F*

and S HUBERSON

*Laboratoire de Mécanique, Université du Havre, BP 540, 76 058 Le Havre, F*

**Summary**

This paper deals with adaptation and improvement of a previous model developed to predict amount of pesticide deposit within vine canopies. Tasks described here were aimed at analysing the effect of variation in the leaf area density (LAD) on both model predictions and deposits measured in the field. Tests were conducted in a vineyard during spring-summer 2001. Deposits on leaves and LAD were measured at several growth stages. After a description of the field tests, the outline of the model is briefly described and the influence of LAD on the results obtained with both methods discussed.

**Key words**: Vine, spraying, model, deposit, simulation, Leaf Area Density, absorption coefficient, resistance.

## Introduction

Vines, particularly those in Mediterranean countries are infested by various pests and diseases that are controlled by frequent pesticide treatments, usually by means of air-assisted sprayers. It is now necessary to reduce pesticide losses to preserve the environment (i.e. to reduce run-off and drift problems). It is also necessary to spray more accurately in order to decrease the amounts of pesticides in plants as well as to limit possible residues in grapes and/or in wine. These improvements depend on a better knowledge of spraying processes. To understand phenomena that occur during spraying, many experiments have been conducted but they are time-consuming and expensive and, moreover, not reproducible. Operating conditions vary substantially since an exact description of the vine foliage would be obviously impossible and of no use. As a result, averaged conditions had to be defined. They provided a basis for numerical simulations. Within that context, this work aimed at predicting which part of pesticide sprayed within the canopy is retained by leaves, depending on the canopy density.

In a previous paper (Da Silva *et al.,* 2001) a model was described that represented air penetration of air-assisted spray within vine canopies. The model was constructed according to principles developed by Walklate (1996) and measurements of air velocities performed in the laboratory on artificial plants. The steady, incompressible and isothermal flow could be described by the time-averaged Navier-Stokes equations (Zhi *et al*., 1996). Product concentration within the canopy had been predicted by means of an additionnal advection-diffusion equation. The different physical parameters which were used in this equation had been identified in order to reproduce the results obtained on vine leaves during a one-spray test with a fluorescent dye, where all leaves from a vine were picked to measure deposits.

In this paper, the aim is to analyse the effect of LAD on deposits at different growth stages, by two different approaches; field tests and model simulations.

## Materials and Methods

### *Field Experiments*

Tests were organised on a Merlot grape vineyard of 3.3 hectares area. The test period extended from May 15th to July 15th 2001. During this period, this vineyard was sprayed 3 times with copper using a pneumatic sprayer at a dose of 1.5 kg $ha^{-1}$. Calibration was done in laboratory to obtain a flow rate of 3 litres $min^{-1}$ from each side of the sprayer. The forward speed was 5 km $h^{-1}$ (Fig.1).

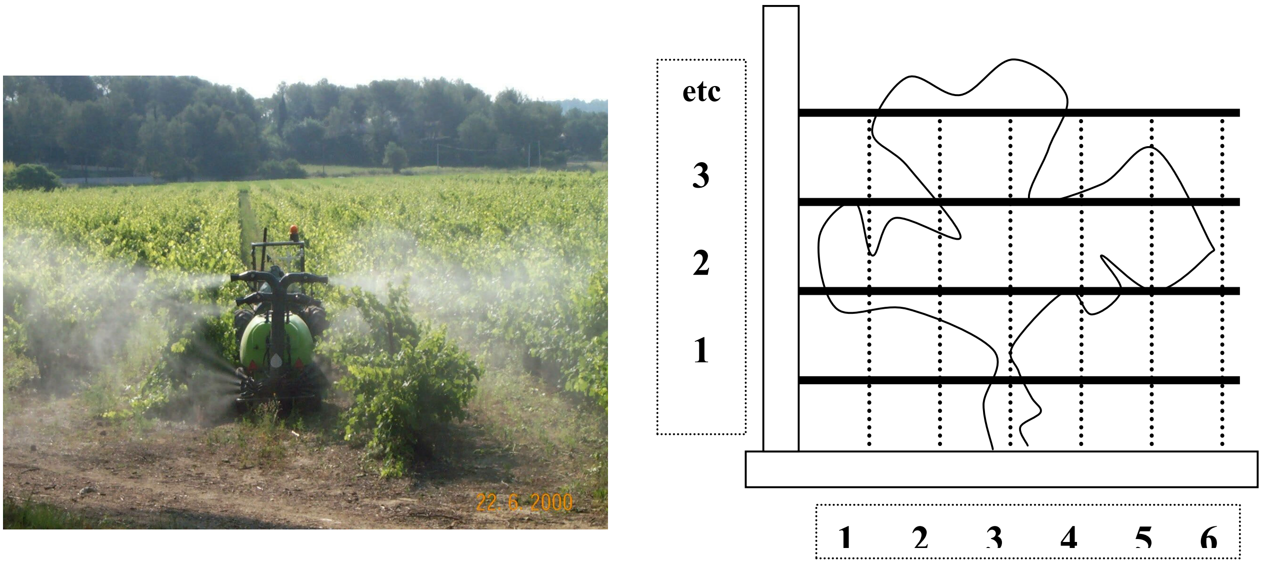


Figure 1. *Field experiments: photograph of spraying and frame for leaf sampling*

That sprayer was equipped with an embedded device to record meteorological data, right and left flow-rates and ground velocity and with a GPS device to record sprayer position. Set-up of the sprayer was the same for all three tests except those examining the effects of direction of the spray jets.

Leaves were collected from 3 trees before each spray application and from 9 trees after each application. For each tree, canopy sections of 10 cm width (travel direction) were selected. These sections were then divided into 25cm x 25cm x 10cm cells (Fig.1).

For each tree, leaf areas were measured using a camera and an image analysis procedure developed with Matlab. The leaf area density (LAD) was then computed for each cell. The amount of copper was obtained by digesting the organic matter with acid followed by flame atomic absorption spectrometry. Results were given for the entire mass and that mass was related to surface area (efficiency) for each harvested cell.

The model, developed with CFX solver was described in Da Silva (2001). Contrary to this last paper, the vine was now considered to be non-homogeneous. Its geometry has been divided in 5 vertical blocks in which leaf area density was defined (Fig. 2). The numbers of cells in the vertical, longitudinal and transversal directions are respectively 40, 35 and 24 for the all domain and 20, 20 and 24, for the vine.

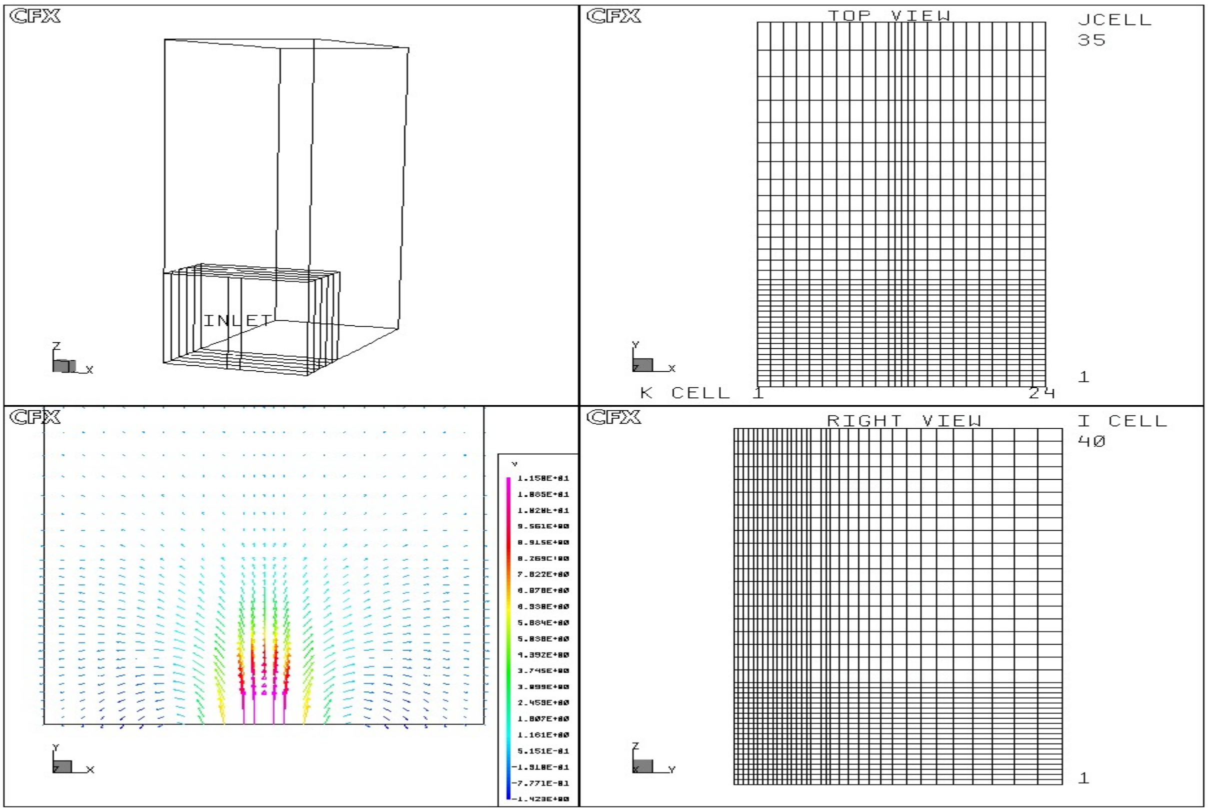


Figure 2. *Geometry. Top left, global geometry. Top right, grid from top view. Bottom right, grid from right view. Bottom left, simulation air flow.*

Air velocity at the inlet of the domain was set to 11.5 m $s^{-1}$ corresponding to the averaged experimental conditions described in the previous section. On the other faces, Dirichlet boundary conditions for pressure were used. Total pressure was specified and set to 0.0 bar.

As previously mentionned, the physical phenomena has been described by means of two different equations. Firstly, the Navier Stokes equation was used with the additional resistance tensor $R_{ij}$ causing a momentum loss due to foliage proportional to the LAD, as shown by Walklate (1996). Secondly, regarding the product transport, an advection-diffusion equation described the concentration decrease across the canopy by introduction of a sink term $S_c$ equal to $S_p.Y_a$ where $Y_a$ is the product mass fraction (Da Silva *et al.,* 2001). There was only one carrying phase, air, which was regarded as a continuum and solved in an Eulerian frame. $R_{ij}$ and $S_p$ were specified in each block and $Y_a$ , the initial mass fraction of the product, was set at the inlet.

In order to compute the deposit within a non-homogeneous vine canopy, i.e. with a non-uniform LAD, it was then necessary to estimate the product concentration in the five vertical blocks used in field measurements. In the numerical simulation, the sprayer was static so that the air jet only occupied a limited part of the computational domain. Therefore, a reduced section of the cross flow plane was selected, extending vertically from lines 1 to 22 and rows 7 to 18

(Fig.2). In order to perform a computation, each block had been sub-divided into four brackets extending 0.0625 m in the flow direction and corresponding to a convenient discretisation for the numerical simulation. For each block, constant values for the resistance and absorption coefficient had to be specified (Fig. 3).

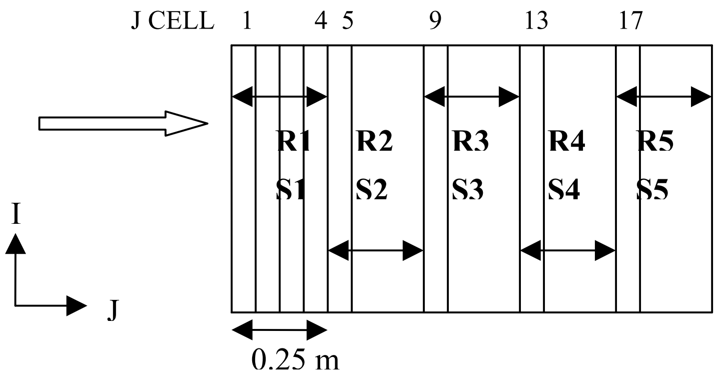


Figure 3. *Sampling of the vine*

On this basis, block values for Sp were selected in order to fit the experimental data as well as possible. This was performed by means of a set of runs which actually constituted the different steps of a rough optimisation procedure. The main assumption at this stage was that the optimisation could be parabolised according to the flow direction. This is a realistic requirement since the concentration had no effect on the flow in our model. The different sections are coupled within the concentration transport equation only, which could be considered as a weak coupling in view of the respective values of the transport velocity and dispersion coefficient. Therefore, the following sequence had been performed:

We assumed that all the Sp values for block 1 to n-1 had been computed. A first run with these values for the upstream blocks and Sp = 0 for the downstream blocks including block n was then performed. A first estimate for Sp(n) was computed from the local concentration in block n. This value could be used as a first guess in an iterative procedure in which the upstream and downstream values were those previously used and only the block n value was adjusted. Local iterations were stopped once the desired deposit value had been conveniently approximated. It was important to notice that the concentration fraction corresponding to the deposit had to be renormalised since the experimental deposit fraction was based on the initial concentration whereas the computed one was based on local concentration.

The procedure was stopped when coefficient Sp had been estimated for all blocks.

## Results

### *Field results*

Analysis of results was done in three steps. The first was to compute an average tree for each test (May, June and July), the second was to analyse the balance of copper for each growth stage and the third was to analyse influence of LAD and of growth stage on distribution of product within the plant.

To define an average tree at the three periods, it was first necessary to have each tree centred around its baricentre. This baricentre was obtained by using LAD as a mass parameter. Then, LAD and the mass of copper were re-computed with a linear interpolation so that all trees of the same test had the same baricentre. Then, the average tree was defined to have in each of its cells the average values of LAD and of copper mass of each cell in the same position for any tree at the same period. Table 1 gives the mean LAD obtained for each average tree as well as the total amount of copper sprayed on it. This last value was computed by subtraction of the amount of copper measured just before spraying and it is given relative to one hectare (with rank space of 2.50 m).

Table 1. *Mean LAD and mass at of copper obtained at the three different growth stages (amount of sprayed copper: 1500 g/ha)*

| Test | Height (m) | Depth (m) | Mean LAD $m^2/m^3$ | Mass of Copper g/ha | Percentage of sprayed Cu |
|---|---|---|---|---|---|
| May | 0.75 | 0.75 | 0.76 | 95 | 6% |
| June | 1.25 | 1.50 | 2.34 | 574 | 38% |
| July | 1.25 | 1.50 | 3.30 | 1141 | 76% |

Figure 4 shows the amount of copper measured on leaves relative to LAD for the three different growth stages. The values are for the total amount obtained in each collect cell (25cm x 25 cm x 10 cm). The scheme was drawn on a log-log scale because samples with low LAD (and low mass of Copper) were more numerous.

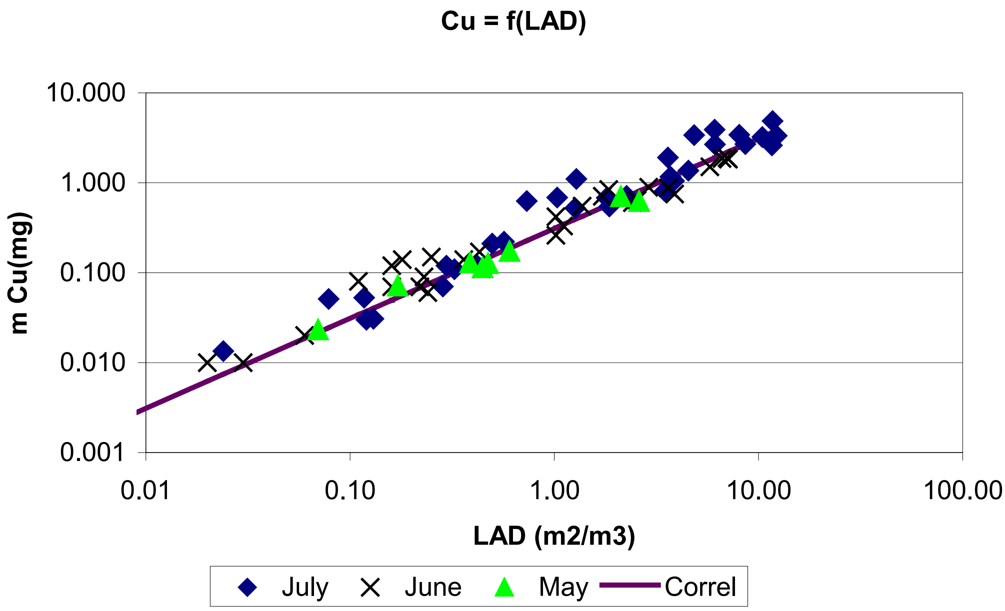


Figure 4. *Amount of copper measured in each cell of the averages trees for the three growth stages (May, June and July) - mCu (mg) - relative to the LAD. "Correl" stands for the linear regression curve*

*Simulation*

The model had been calibrated in former trials made in a vineyard with an air-assisted sprayer (Da Silva *et al.,* 2001). Improvement of model consisted of dividing the vegetation into 5 blocks of 4 brackets each one, with a different resistance force and an absorption coefficient for each block, in order to have LAD varying with depth. In CFX solver, the resistance called $R_f$ is equal to $R_{ij} / (U_i U_i)^{1/2}$ where $U_i$ is the i-component of the air speed. It is proportional to LAD. With successive simulations, as described above, values of $S_p$ were calibrated to fit the experience (Fig.5).

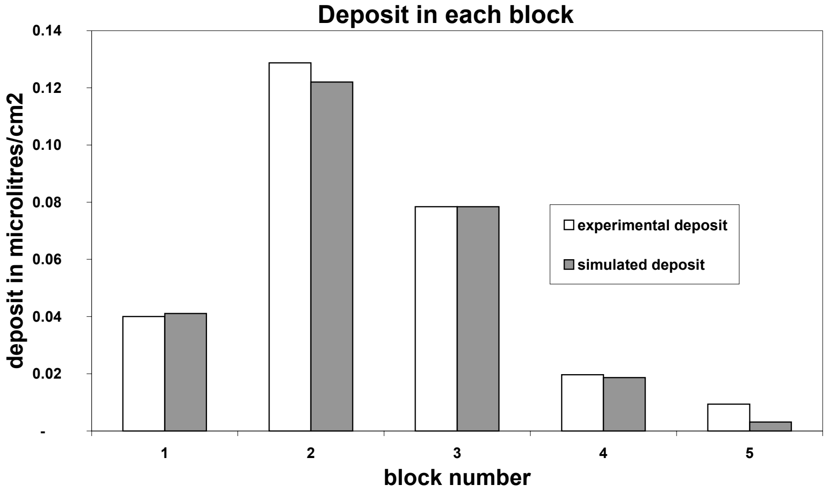


Figure 5. *Comparison between experimental and simulated deposit.*

Values of $S_p$ (S1 to S5) and $R_f$ (R1 to R5) are recapitulated in Table 2.

Table 2. *Simulation results relatively to LAD : values of $R_f$ and $S_p$ coefficients and evolution of the initial concentration Co at the input of each block.*

| | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 |
|---|---|---|---|---|---|
| LAD ($m^{-1}$) | 0.09 | 3.34 | 3.06 | 1.93 | 0.32 |
| $R_f$ ($kg.m^{-4}$) | 0.03 | 1.22 | 1.12 | 0.7 | 0.12 |
| $S_p$ ($kg.m^{-3}.s^{-1}$) | -0.2 | -15 | -18 | -30 | -100 |
| Co ($g.m^{-3}$) | 17.88 | 22.52 | 10.32 | 1.06 | 0.02 |
| Deposit ($g.m^{-3}$) | 0.04 | 4.08 | 2.40 | 0.36 | 0.01 |

While resistance $R_f$ increases with LAD, absorption coefficient decreases linearly together with LAD, except for the first block, where the LAD can be overlooked. As far as concentration Co at the input of each block is concerned, i.e. concentration before deposit as explained in simulation principles, it decreases exponentially from second to last block. Between the first and the second block, one can see an accumulation of product, Co passing from 17.88 $g.m^{-3}$ to 22.52 $g.m^{-3}$. Apart from the first block, deposits decrease with depth while increasing with LAD.

## Discussion

### *Field experiments*

The main fact that can be underlined about field results is a poor proportion of copper reaching the plant, particularly at the first growth stages. The reason is that the dose of product was not adaptated to the plant size. Only the direction of the spray jets was modified. These results show clearly – if necessary – that this is not good practice. In fact, product was lost mainly to the ground and the atmosphere.

Evolution of geometry and density of canopy is important during the first month. Later on, it becomes less important but one should notice that some operations as pre-pruning or stems training were conducted during the second month.

When observing the influence of LAD on the amount of copper retained on leaves, one can observe that the growth stage does not seem to influence behaviour. The linear regression gives a correlation coefficient of 0.90. This regression fits the equation :

$m_{Cu/cell}$ [mg] = 0.31 x LAD [$m^2/m^3$]

Such a result seems to demonstrate that collecting from canopy sections of 10 cm width at several points in the vineyard in order to define an average sample is a good methodological approach as it allows a generalisation of some phenomena. This point is very interesting when justifying use of simulations as there were done. The linear correlation that was observed could be due to the spraying technology used (pneumatic). It is not obvious that another sprayer would have given the same result. Nevertheless, such kinds of results should be confirmed under different conditions (sprayer and dose) as it could allow easy prediction of amounts of deposits.

*Simulation*

The first effect of LAD is decreasing the air speed. With the second block, when LAD abruptly changes, there was an accumulation of product because of foliage shear stress. It is illustrated by $R_f$, depending only on LAD.

In order to modelise the fraction of product retained by the leaves, the absorption coefficient Sp has been introduced in the folowing advection-diffusion equation :

$$\frac{\partial \rho Y_a}{\partial t} + \nabla.(\rho U Y_a) - \nabla.(\Gamma_a \nabla Y_a) = S_p Y_a$$

where :

$\rho = \rho(\text{air+ product}) = Y_a \rho_a + (1 - Y_a)\rho_{air}$

$Y_a = \frac{C_a}{\rho}$, with $C_a$ the concentration of pesticide

U is the air speed and

$\Gamma_a$ is the molecular diffusivity added to the turbulent diffusivity.

Although an identification procedure based on experimental measurements had been used, it was not possible to obtain satisfactory results with one uniform value for Sp. This was only achieved when a linearly varying Sp was used. However, such a law can not be considered anymore because it is based on one single experiment.

Several simulations calibrated after many experimental data (with other vine and machine configurations) could possibly confirm it. If $S_p$ could be deduced from LAD, final deposit could be predicted from known LAD using the advection-diffusion equation model.

*Influence of LAD*

The experimental results shows a linear correlation between LAD and deposit, meaning that the deposit per leaf surface unit should be constant for an average tree representing the entire vineyard. The goal of the numerical simulation was to describe what happened on a given tree knowing its internal LAD variation. The representation used here, with an advection-diffusion equation using a sink term $S_p$ allowed representation of experimental deposits but calibrations for simulations resulted in a cumbersome procedure. Moreover, the clear dependance of Sp on the LAD can not be considered as defined due to limitation of the present work to one single experimental case. Further work will be required to derive an automatic identification procedure which can be used to analyse many more experiments so that the resulting Sp (LAD) law could have a better basis.

A Lagrangian model would allow analysis of the dependency of the phenomena on droplet speed and diameter. With such an approach, a droplet mass fraction could be defined instead of the product mass fraction used with the Eulerian model. It shoud be then possible to analyse a collection efficiency of spray droplets as defined by Zhu (1996) on vertical targets.


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