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Test Method for Boom Suspension Influence on Spray Distribution, Part II: Validation and Use of a Spray Distribution Model

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Abstract

In the first part of this paper, an experimental study of the influence of boom movements on ground distribution showed that a geometric static model should correctly be used for simulations. Such model was developed in Cemagref. The objective of this second part is to validate the results of this model for several kinds of excitation in laboratory and field conditions: laboratory validation used a conveyor and a shaking platform to reproduce pure vertical and horizontal movements; field validation was assessed on both concrete and field tracks to analyse combined movements. Then the model was used to define an evaluation method for sprayer boom behaviour at farm level. The concept is for the sprayer to travel over a bump, to measure boom movements and to simulate the distributions. The evenness is assessed through the coefficient of variation (CV) and the percentage of area correctly sprayed.

Keywords: sprayer, distribution, nozzles, boom, validation

1. Introduction

This study was part of a European project (SPECS, 1998) to develop a boom test method at the farm level. This method should allow to test the performance of sprayers in use relatively to the uniformity of the ground distribution and to give advice for rapid corrections. Processing speed, easiness of use, accuracy and cost considerations were the key points of this project.

In the first part of this article (Lardoux *et al.*,2007), an experimental approach was described for the analysis of the importance of the main movements on the distribution. Roll and yaw movements were shown to have important effects on unevenness and it was concluded that, when these movements are uncoupled, a geometric representation should be able to predict ground distributions with sufficient accuracy. If such conclusion could be enlarged to the combined movements of the boom, an efficient test method could then follow the following steps: apply appropriate mechanical excitation on the sprayer, measure boom displacements and model ground distribution. With a model of low complexity (i.e. with no necessity of heavy means of computation and with a friendly interface), such protocol should allow results to be obtained quickly when an experimental approach based on distributions measurements would be very much longer to setup and less reproducible.

The main objective of this work was then to check the ability of a low complexity model, based on a geometric representation of the sprays, to predict distributions for uncoupled and for combined movements of the boom. Then, appropriate mechanical excitations to test the sprayers were discussed and a test method was designed both for the excitation and for boom measurements at the farm level. Finally, the ability of the combine use of these methods (mechanical excitation, boom measurement and simulation) to estimate the behaviour of the booms at the farm level was assessed.

2. Materials and methods

2.1. *Distribution model*

To compute distribution on soil knowing boom movements, a geometric approach can be proposed as in De Baerdemaker *et al.* (1983), Chaplin and Wu (1989), Ramon and De Baerdemaeker (1996), Pochi and Vanucci (2002) and Lebeau (2003). Such a model was also developed in the Cemagref institute (the French Institute for Agricultural and Environmental Engineering Research) by Sinfort *et al.* (1994). This model can predict spray distributions under a moving boom in a two-dimensions. The simulation software inputs are the boom movements and tables of nozzle flow-rates compiled with measurements made with a patternator, at several heights. The 2D distributions are estimated on a plane rectangular surface divided in elementary cells of 50 mm x 50 mm in size, from the successive positions of the nozzles, obtained from measured positions of the boom.

The distribution of each nozzle is described with one dimensional patterns of 50 mm elements. These patterns are modified depending on the height and the vertical angle of the nozzle. The flow-rates constituting the patterns are distributed in the cells dividing the ground surface. The principle is synthesised in *Fig. 1*.

2.2. *Validation tests*

To validate the model described above, it was proposed to compare measured and simulated distributions for movements obtained in controlled conditions. Two validation steps were proposed. The first one used a conveyor able to shake the boom with roll or yaw oscillations during its ride (uncoupled movements). The second one was based on riding tests on tracks, allowing to obtain combined vertical and horizontal movements. The measurement method for the distributions was the same as the one used in the first part and described in Enfält *et al;* (1997). It uses image analysis of papers sprayed with Nigrosine water soluble. This method gives accurate and rapid results but under-estimates the doses when the height of the boom increases, probably because of the calibration step and maybe also because the evaporation increases with the distance travelled by the droplets. To compare measured and simulated distributions, the percentage of area with correct, over and under spraying (the correct treatment was defined with +/- 15% from the mean sprayed dose (Sinfort *et al.*, 1994) and the coefficient of variation (CV) were used. As seen in the first part, we also defined another indicator, (S_p), based on the definition of scalar product of histograms used in image analysis methods as a correlation coefficient between two images (Rabatel, 1991):

$$S_P = \frac{\sum_i m_i m_i'}{\sqrt{\sum_i m_i^2 m_i'^2}} \qquad (1)$$

where m_i is the proportion of cells behaving to the i[th] class of amount of product (or of grey level) for the first distribution (or the first image) and m'_i is the same for the second distribution (or the second image).

2.2.1. *Uncoupled movements*

The conveyor with its shaking-platform was described in the first part of this article. The experimental study already showed that static distributions (equivalent to simulations with a horizontal boom, without any roll or yaw movement) were in good agreement with the measured ones although velocity effect and interactions between sprays are not considered. The results of the models were then compared with experimental distributions for roll and yaw movements.

+/-5° oscillations were reproduced for roll and yaw at several frequencies: 1.08, 0.77 and 0.49 Hz. These movements were tested with two forward speeds: 6 and 10 km/h. Boom height was 50 cm and the nozzles were

Teejet XR 11004VS. Boom positions were registered from the command device of the shaking platform. Distributions were obtained on an area of 4.50 m in the forward direction and 4.45 m wide.

2.2.2. *Combined movements*

Within the SPECS consortium, two tracks were selected to obtain combined movements: the 100 m long concrete standard test track for seat tests built in Cemagref, Anthony, France according to ISO 5008 standard (bumpy track) and a 47 m ploughed field track covered with grass which topography was measured every 15 cm along each wheel path (ISO, 1979). Three sprayers were tested: two were of same type (A) with a new and an old one, the third one was a new one of another type (B). The type A sprayers were mounted ones and their booms were 12 m long while the type B sprayer was a trailed one with a 15 m boom. The three sprayers were tested on the bumpy track with three replicates but only the new type A sprayer was tested on the field, with one replicate only because the field topography was modified by the passage of the sprayer. Forward speed was 6 km/h and the tank was almost empty. Distributions were obtained by spraying Nigrosine mixture on papers placed along the tracks during the tests (*Fig. 2*) and by simulation. The measurement area was placed under the right part of the sprayer and sized at 8.95 m in the driving direction for a 4.25 m width. To measure the boom positions necessary for the simulations, the tracks were reproduced on the track simulator built in Cemagref Montpellier and already described in Sinfort and Bonicelli (1989). This device moves vertically the front and the rear axles of the tractor with four hydraulic servo-jacks that reproduce the varying altitudes of the track as if the tractor was travelling along it. Boom tip movements were measured with a device using an infrared sensor described in Sinfort *et al.* (1994). Roll and yaw movements were computed from these measurements knowing the position of the boom centre. This latter was obtained from the command part of the simulator. To run the model software, the distributions of the XR04 nozzle were measured on a patternator consistent with ISO 5682 standard, at several heights from 0.20 m to 1 m, every 0.1 m (ISO, 1981).

3. Results and discussion

3.1. *Uncoupled movements*

3.1.1. *Yaw movement*

Grey level representations of the experimental and modelled distributions are shown in *Fig. 3* in association with the boom rotation angle, for the test at 0.77 Hz and 6km/h. Forward direction is from the top to the bottom of the figure. These distributions look similar: the model correctly predicts the areas over-sprayed, when the boom velocity decreases.

Results of analysis are given in Table 1. As expected, mean doses are under-evaluated for experimental results but they remain constant for all the tests.

The coefficients of variation, CV, the over, under and correctly sprayed areas, are very similar in experimental and simulated distributions. The values for the CV are about 40% and correctly spray areas about 30%. The scalar products of histograms S_p are all greater than 0.97 confirming the similitude of the distributions.

3.1.2. Roll movement

Here again important similitude appears between simulated and measured patterns (example in *Fig. 4*) as confirmed by the scalar products of histograms S_p given in Table 2. Spray unevenness due to nozzle overlap are correctly reproduced. However, some over-sprayed zones are not reproduced. This can be explained because the experimental method gives variable doses depending on the height although the model always computes the same dose.

Nevertheless, as shown in Table 2, the model gives higher CV values and lower percentages of correctly sprayed areas.

3.2. *Combined movements*

An example of experimental and modelled distributions is shown in *Fig. 5*, for the sprayer type B on the bumpy track. The model correctly reproduces the positions of the five over-sprayed areas measured but some of them are slightly shifted. More generally, the simulated distribution is less even than the measured one. The correlation coefficients, although smaller than in the previous tests, remain acceptable: roundly 0.90 (Table 3).

Table 3 shows that the performances of each sprayer relatively to the distribution are variable: on the bumpy test track, the trailed sprayer type B gives the most even distributions. Obviously, the old sprayer has worse CVs than the new one and better behaviour is observed on the field track, which was much smoother than the bumpy one. The same tendencies are observed from experimental and simulated patterns.

The same differences between measurements and simulations are always observed: higher doses, higher CVs and smaller correctly sprayed areas on the simulations. Measured doses show great variations (20% for the old type A sprayer) but it maybe comes from the distribution measurement method. For the measured distributions, the CVs are between 20 and 35%. The differences on the values of the CV between simulations and measurements are more important (about 10%). An explanation is that the command of the track simulator uses squared signals and does not take the smoothing effect of the tyres into account. Mechanical excitations are then always higher than in real conditions. Furthermore, the method does not consider the deformations of the boom as only the tip of the boom positions are measured. The boom is then supposed to be rigid and the displacements of the nozzles are consequently over estimated. Spray dynamic effect could also have a smoothing effect that is not taken into account by the model.

The model could be improved by using a one-dimensional patternation of nozzles in dynamic conditions. These new data would be compatible with the present software. Moreover, a stochastic approach could be added to take into account the intensity of wind turbulence

4. Definition of a field sprayer test

The simulations give worse results than measurements, but this can be explained by the imperfections in the step calibration of the measurement method and in the reproductions of the movements with the track simulator. Taking into account the good results of the model for the laboratory tests, the model was assessed to correctly reproduce the evenness of the distributions and to predict the behaviour differences of the sprayers. It was then necessary to find a way to shake the sprayers and to obtain boom displacements in a way compatible with the objectives of the project: use at farm, low cost, robustness, test repeatability.

Several methods were already developed to test field sprayer movements. Some authors proposed to test the sprayers directly in fields conditions, with measurements of boom accelerations (Speelman & Jansen, 1994) or boom displacements with laser sensors (Vannuci *et al.*, 1992). But this method did not comply with the requirement of repeatability. Langenakens *et al.* (1995) used hammer tests on the boom to provide a modal analysis of its dynamics behaviour and simulate movements and then distributions for some standard configurations. Here, it is proposed to use a more global method, based on driving the sprayers on a simple bump placed on a rigid flat track (concrete or macadam, for instance). Acceleration and deceleration distances can be very short (2 m) and a distance of 15 m is enough to perform a test. A pyramidal bump shape was selected to create a large band frequency signal able to excite all the resonance frequencies of any tested machine. Movements are measured with an image analysis device that detects a target fixed on the boom tip. This method was described in Sinfort *et al.* (1998); a picture and a chart showing its principle are given in *Fig. 6*.

A spraying test was organised for the new sprayer *A* with the experimental method of Enfält *et al.* (1997) to check if, with this testing method, the distribution model could give a correct result. The resulting distributions are shown in *Fig. 7* with the over, under and correctly sprayed areas. After the bump, the boom had two important horizontal oscillations. They were responsible of two over-sprayed areas as observed in both measured and simulated distributions. In the measured distribution, longitudinal unevenness appears due to the overlap of the nozzles. In the simulated distribution, the effect of the boom movements are highlighted, giving transversal unevenness which was not measured. The value for the scalar product of histograms S_p, corresponding to the measured and simulated ground spray distributions, is 0.9217, confirming that the similarity of the distributions is acceptable.

The values obtained for the CV are 53% and 64% for the measured and modelled distributions, respectively, while the percentages of areas correctly sprayed are 41% and 18%. This confirms that the measurement method under-estimates the unevenness while the model approach over-estimates it. Here again, the measurement of the boom positions, which is based on the detection of the boom tip, can be a cause of error as it does not consider the deformations of the boom. This error becomes more important with the largest booms due to the articulation joints between the sections. The model should then not be used to obtain realistic values but it is expected to give good discrimination between different behaviours.

It was then proposed to test the method with numerous used sprayers with varying frames (Sinfort *et al.*, 1998). The values for the CV of the spray deposit distributions was found to vary from 13 to 34% showing that the proposed method was sensible enough and then suitable for the objectives of the project.

5. Conclusion

The results show that the model gives very good predictions for laboratory tests with pure vertical and horizontal movements. For combined movements, modelled and measured distributions have the same features but the same differences are always observed: lower doses, lower values for the coefficient of variation and higher surfaces with correct spraying for measurement distributions. Three combined factors are mainly responsible: the calibration step of the measurement method for the distributions, the method for the boom position measurements that consider that the boom is rigid and the spray dynamic effect which is not taken into account. Nevertheless, this geometric approach is a satisfactory method to quickly estimate the ground spray distribution under a rigid moving boom. The model could be improved with the use of dynamic nozzle patterns and with an estimation of the turbulence effect.

The proposed method, using a bump test appears to be a good compromise to test field sprayers in use at the farm level and complies with the given requirements. The results over-estimate unevenness and the deformations of the boom should be taken into account to a better assessment of the behaviour. For instance, the quality of the measurements could be improved by measuring movements at each section tip of the boom. Overall, the simulated distributions, that highlight the behaviour of the booms, provide an interesting tool that fulfils the objectives of the project.

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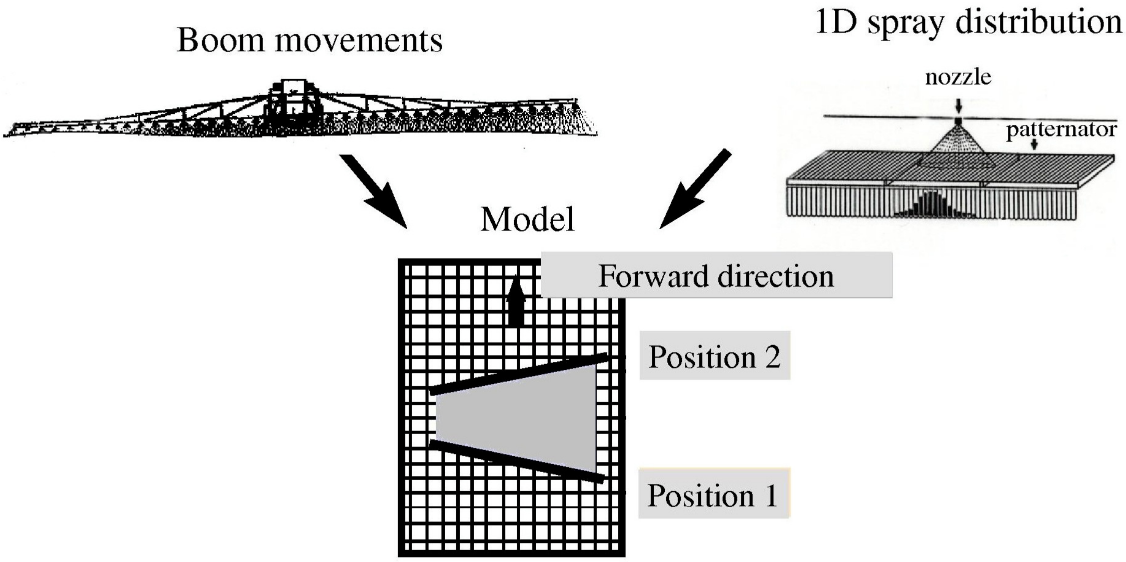

Fig. 1. Dynamic ground spray distribution model

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Fig. 2. Experimental test on concrete track

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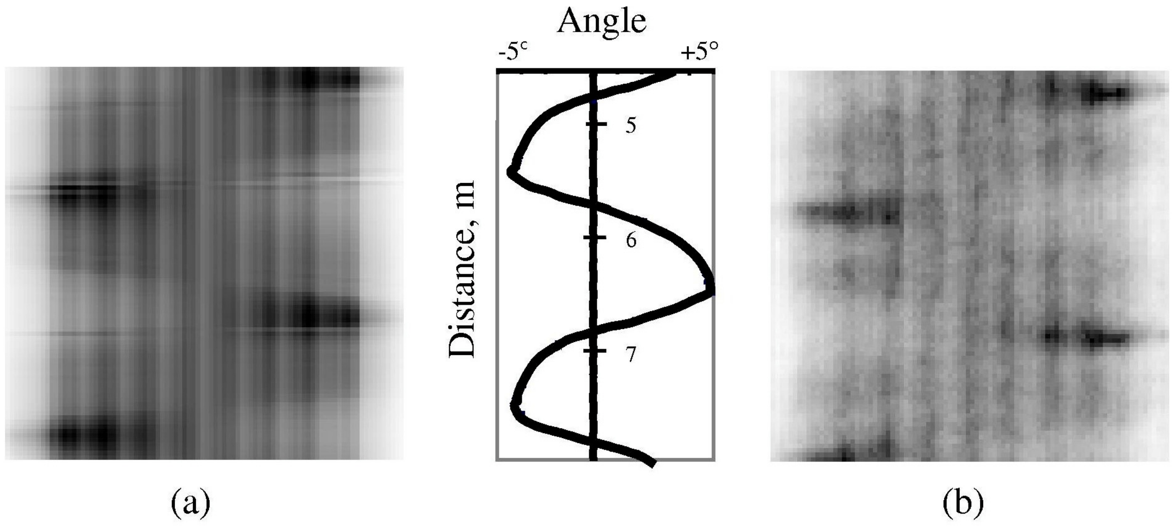


Fig. 3. Comparison between (a) simulated and (b) measured spray distributions for yaw movements: frequency of 0.77 Hz, travel speed of 6 km/h and boom height of 0.5 m

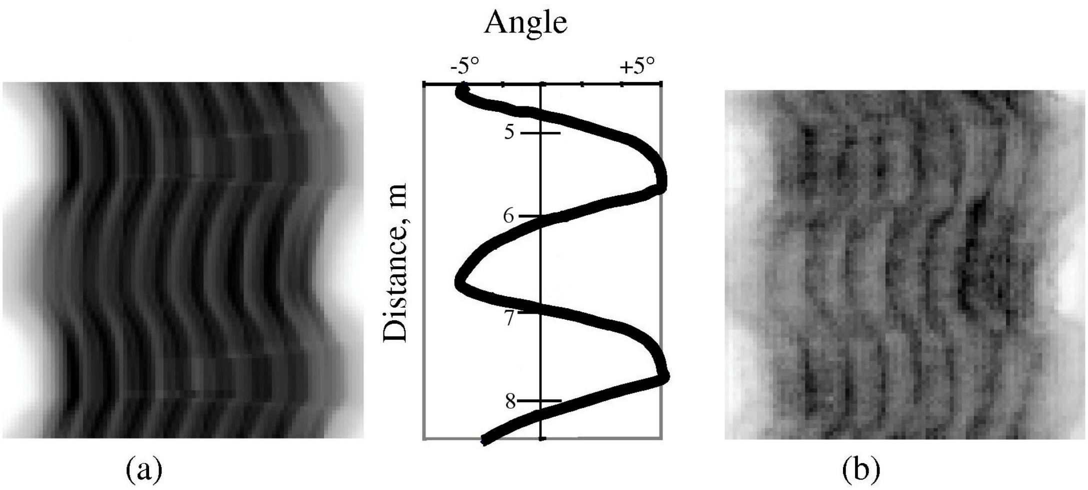
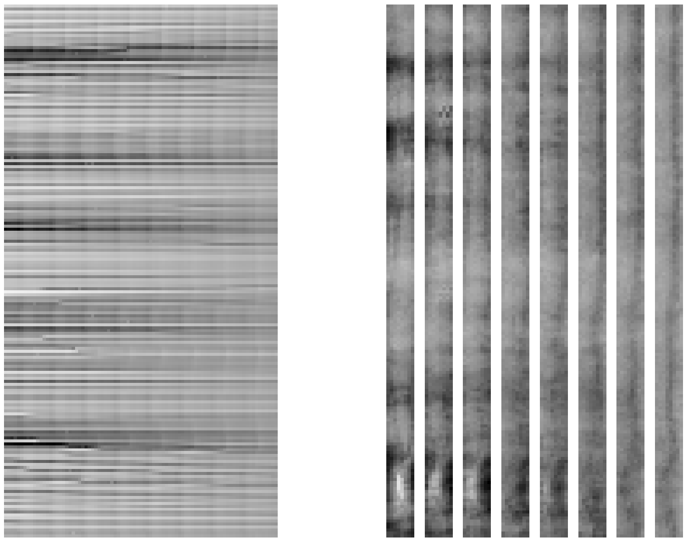


Fig. 4. Comparison between (a) simulated and (b) measured spray distributions for roll movements: frequency of 0.77 Hz, travel speed of 6 km/h and boom height of 0.5 m



(a) (b)

Fig. 5. Comparison between (a) simulated and (b) measured spray distributions on the bumpy track (sprayer type B)

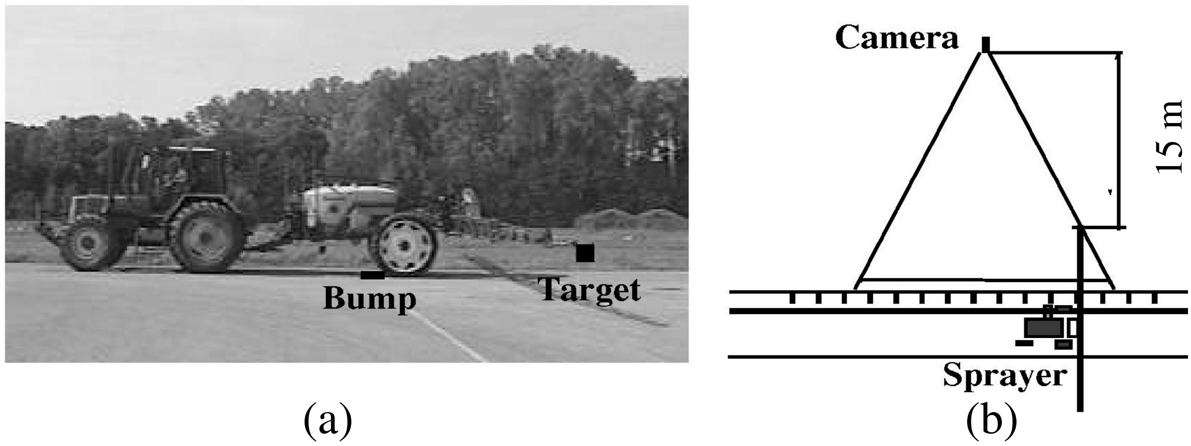


Fig. 6. Principle of the bump test: (a) test picture; (b) organisation chart

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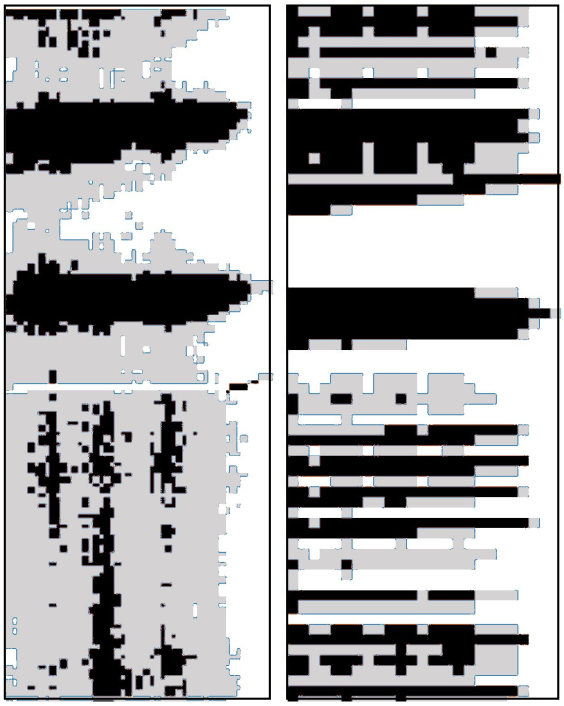

(a) (b)

Fig. 7. (a) Measured and (b) simulated distributions obtained on the bump test with the new sprayer A, at 6 km/h: black, over-sprayed areas; grey, correctly sprayed areas; white, under-sprayed areas