Effect of the entrained air and initial droplet velocity on the release height parameter of a Gaussian spray drift model

C. STAINIER [a], V.ROBAYE[a], M-F DESTAIN[a], SCHIFFERS [b], F. LEBEAU [a]

Gembloux Agricultural University, [a]Unité de Mécanique et Construction, [b]Laboratoire de phytopathologie,
Passage des Déportés 2,
B-5030 Gembloux, Belgium
Tel: 32.(0)81.62.21.60 fax: 32.(0)81.62.21.67. E-mail: stainier.c@fsagx.ac.be

Abstract

The increased concern about environmental effect of off-target deposits of pesticides use has resulted in the development of numerous spray drift models. Statistical models based on experimental field studies are used to estimate off-target deposits for different sprayers in various environmental conditions. Random-walk and computational fluid dynamics (CFD) models have been used to predict the effect of operational parameters and were extensively validated in wind tunnel. A third group, Gaussian dispersion models have been used for several years for the environmental assessment of the pesticide spray drift, mainly for aerial application. When these models were used for the evaluation of boom sprayer spray drift, their predictions were found unreliable in the short range, were the initial release conditions of the droplets have a significant effect on the spray deposits. For longer ranges, the results were found consistent with the field measurements as the characteristics of the source have a reduced influence on the small droplets drift. Three major parameters must be taken into account in order to define realistic initial conditions of the droplets in a spray drift model: the spray pattern of the nozzle, the boom movements and the effect of entrained air and droplet velocities. To take theses parameters into account in a Gaussian model, the nozzle droplet size distribution measured with a PIV setup to divide the nozzle output into several size classes. The spray deposits of each diameter class was computed for each successive position of the nozzle combining the nozzle spray distribution with drift computed with a Gaussian tilting plume model. The summation of these footprints resulted in the global drift of the nozzle. For increasing droplet size, the release height used in the Gaussian model was decreased from nozzle height to ground level using an experimental law to take into account the effect of entrained air and droplet initial velocity. The experimental law was adjusted on 2m/s wind tunnel measurements and robustness was evaluated for 1 and 4 m/s.

Key words: drift, Gaussian tilting plume model, spray nozzle, droplet spectra

Introduction:

Gaussian dispersion models have been used for several years for the environmental assessment of the pesticide spray drift, mainly for aerial application. These models were used for long ranges evaluation of boom sprayer spray drift and the results were found consistent with the field measurements as the characteristics of the source have a reduced influence on the small droplets drift. For short range spray drift deposits estimation, their predictions were found unreliable due to the significant effect of the initial release conditions. The objective of this research is to improve the short range estimation of Gaussian model adapted to spray drift.

The Gaussian model described in Stainier et al. (2006, 1) uses three major parameters in order to define realistic initial conditions of the droplets in a spray drift model: the spray pattern of the nozzle, the boom movements and the effect of entrained air and droplet velocities expressed by the adjusted release height (Hs). Both first parameters values are measured, the Hs value has to be fitted regarding experimental drift measurements.

Material and methods

Wind tunnel trials

Wind tunnel and spray drift deposits measurements were made using water and following the same protocol that described in Stainier et al. (2006, 2). By the way, two modifications were made: the air flow parameters were: wind speed (2m/s±1%), relative humidity (70±1%) and temperature (20±1°C) and 36 collectors were used to have high precision drift curve. 28 collectors were aligned from 0.75m before the nozzle to 1.95m downwind every 10cm. the distance for the last 8 collectors, placed from 2.45m to 5.95m, was 0.5m.

Droplet size and spray pattern

The droplet size measurements are made using a Particle Imaging Velocity (PIV) setup similar to XXX material. The result of the image processing gives the part of the volume observed for each of the 20 granulometry class for a given position. The spray pattern is generated when moving the nozzle along a 5x5 cm matrix resolution. 20 different spray patterns are obtained for the entire spray.

Boom movements

The wind tunnel trials are realized with a moving boom in order to include the dynamic effect on the spray observed by Lebeau (2004). The boom displacement is controlled using a servomotor so, at any time, the position and speed of the nozzle is known.

Modified discharge height (Hs):

The modified discharge height reflects the nozzle height less the distance travelled by the droplets from the nozzle under the effect of their initial speed, vertical drag force and gravity.

Three methods to estimate Hs are compared:

The first one used an analogy with Miller (1996) to estimate the length to be subtracted from the nozzle height *(h)* in the proposed model to evaluate *Hs* as a function if the droplet diameter. Modifying Ghosh and Hunt (1994) equations, it is possible to estimate a distance from the nozzle where the droplet decelerates to a fixed velocity. It is assumed that under that critical velocity, the droplet is subject to drift transport. The value of the critical velocity has to be adjusted. *Hs* is evaluated for each droplet class with the ratio between ejection speed and the critical speed as the parameter to fit.

The second method is to use an empirical equation that reflects the decrease of the modified discharge height regarding the droplet diameter (d):

$$Hs = h \cdot \left(1 - e^{-A/d}\right)$$

In order to fit the parameter A, the model was runned with different A values and was compared to experimental drift measurements.

The third method is to calculate the real fall time of each droplet class using Stokes law for a particle having a initial speed. The emission speed is assumed to be the same for all classes (break up sheet velocity). Small particles will quickly reach their sedimentation speed and finish their travel at that speed while largest ones do not decelerate fast enough before hitting the target. Ones the time needed for each class to travel the nozzle height distance is known, Hs is estimated by assuming that each droplet is travelling with its constant sedimentation speed over that time. Smallest droplet class may have Hs higher than h while largest droplets have quite small Hs.

Spray drift tilting plume model

It has be seen that the model can evaluate the spray drift deposits under a moving boom as long as the spray deposits computed under a moving nozzle using a spray deposits model are convolved with the footprint of this nozzle. Furthermore, it has been seen that some of the footprint function parameters are essentially dependent on the droplet size. It is therefore needed to evaluate the footprint of each droplet size, or at least of a sufficient number of homogeneous droplet class independently. The global footprint can then be evaluated as the sum of footprints obtained with homogeneous droplet size class reflecting the spray droplet spectra. At the present stage of research, the footprint function parameters dependence was *evaluated from Fluid mechanics equations and available literature resources on nozzle spray and spray drift characteristics to get a first glance at the model capabilities and limitations.*

Modified discharge height (Hs):

The modified discharge height reflects the nozzle heightless the distance travelled by the droplets from the nozzle under the effect of their initial speed, vertical drag force and gravity. To estimate the length to be subtracted from *h* in the proposed model to evaluate *Hs* as a function if the droplet diameter, an analogy with Miller (1996) considerations was used:

Within the spray fan, smaller droplets slow down faster than larger ones do. Ghosh and Hunt (1994) have estimated the variation of droplet velocity with distance below the nozzle by:

$$V_l = V_{l0} e^{-\lambda(r-r_0)} \quad (3)$$

$$\lambda = \frac{3C_D \rho_a}{8a\rho_l} \quad \text{Where} \quad (4)$$

With V_l: droplet velocity at a distance l from the orifice (m/s)

V_{l0}: initial droplet velocity (m/s)

r: distance from the nozzle (m)

r_0: length of the liquid sheet below the nozzle where droplets form (m)

C_D: drag coefficient

ρ_a: air density (kg/m³)

ρ_l : liquid density (kg/m³)

a: droplet radius (µm)

Modifying the equations (3) and (4) it is possible to estimate a distance from the nozzle where the droplet decelerates to a fixed velocity. It is assumed that under a set velocity, the droplet is subject to drift transport. The value of the velocity has to be adjusted. *Hs* is evaluated for each droplet class with Vl / Vl_0 as the parameter to fit.

In our case, the parameters were estimated respectively as: V_l = 4.6m/s; V_{l0} = 20 m/s; r=0.5 m; r_0: 0.025 m; C_D = 1; ρ_a: 1.293 kg/m³; ρ_l =1000 kg/m³

Particle flow rate (Q_m): The particle flow rate in a particular droplet class was evaluated as the droplet percentage in that class multiplied by the nozzle output.

Dispersion coefficient along y-axis (σ_y) and dispersion coefficient along z-axis (σ_z) : The Dispersion coefficients were set to 0.05 m²/s corresponding to the turbulence intensity on bare ground in stable conditions (Anonymous 2002),.

Mean wind velocity along x-axis (U): The mean wind speed was set equal to 2 m/s.

Sedimentation speed (v_p):. Sedimentation speed of the different droplet sizes was evaluated using strokes law, neglecting the Cuningham correction factor (Reible, 1998).

The drift deposit was computed using Matlab 7.1 (MathWorks inc, Natick, MA) follows next steps:

Based on granulometer measurement, the spray droplet population may be divided into 29 non-zero homogeneous size droplet class (20µm wide classes for example, Hobson et al., 1993)

The spray distribution under the moving boom passing ten times perpendicularly across the wind tunnel was evaluated using the model developed by Lebeau (2004), using the measured static spray pattern.

Each droplet class footprint was computed modifying the size sensitive parameters

Drifted spray deposits for each class are computed as a two dimensional convolution of the product of the percentage of droplets multiplied by the spray distribution with the corresponding footprint

Global drifted spray deposits are calculated as the sum of the drifted spray deposits for every droplet classes.

References

Ghosh S. and Hunt J.C.R., 1994, Induced air velocity within droplet driven sprays, *Proc. Roy. Soc. London A*, vol. 444, 105-127.

Lebeau F., 2004 Modelling the Dynamic Distribution of Spray Deposits, *Biosystems Engineering,* **89**(3), 255-265.

Miller P.C.H., Butler Ellis M.C. and Tuck C.R., 1996, Entrained air and droplet velocities produced by agricultural flat-fan nozzles, *Atomization and Sprays* **6**, 693-707.

Stainier C., Robaye V., Schiffers B., Lebeau F., 2006 (1), Modelling the spray drift by a modified Gaussian tilting plume model, *Aspects of Applied Biology* **77**, 281-287

Stainier C. , Destain M-F., Schiffers B., Lebeau F., 2006 (2), Droplet size spectra and drift effect of two phenmedipham formulations and four adjuvants mixtures, *Crop protection*, in Press