AgEng Oslo 98

EurAgEng

Paper no: 98-A-012

Title:

Spray drift in crop protection: validation and usage of a drift model

Authors:

Holterman H.J.*, Michielsen J.M.G.P., Van de Zande J.C.

Institute of Agricultural and Environmental Engineering (IMAG-DLO)
Wageningen, The Netherlands

Summary:

The IDEFICS spray drift model was developed to quantify downwind ground deposits and airborne spray in pesticide applications using a conventional boom sprayer.
To validate the model, outdoor experiments were carried out using a single-nozzle spraying carriage. The experiments comprised fine, medium and coarse nozzle types at different pressures, and variations in boom height and driving speed. Atmospheric conditions (wind speed, relative humidity and temperature) were recorded during the trials.
The experimental deposits were compared with calculated deposits. Calculated deposits agreed very well with experimental findings for deposits larger than about 10% of the applied dose. At lower deposits the model overestimated ground deposits up to a factor of about 10, at deposits as low as 0.1% of the applied dose.
Model results could be calibrated by regression analysis, after introduction of a normalised distance to account for first-order effects of boom height and average wind speed. The variance in model results compared to experimental results however did not decrease after calibration.
The single-nozzle experiments have high potential in classifying nozzles with respect to driftability for drift-reducing policies.

INTRODUCTION

Chemical crop protection still is inevitable to maintain production yield at a high level. However, unlimited use of pesticides may severely endanger the environment and human health. This possible danger encourages the development and introduction of measures to reduce (a) the amount of pesticides used, and (b) the amount of off-target deposits. In the Netherlands, minimising spray drift to the ground downwind of the sprayed field has specific attention. Especially deposition onto surface water in ditches and canals (being potential drinking water) should be prevented.

In order to assess measures and techniques which claim to be drift-reducing, spray drift must be quantified. Field experiments have the advantage of being straightforward, and results can be interpreted directly to practical guidelines. However, field experiments are laborious and expensive, and the results of those experiments are affected highly by the ever changing circumstances.

Quantifying spray drift by computer simulation is another approach. The IDEFICS drift model (Holterman et al., 1997) was developed to estimate spray drift from conventional field sprayers. Before using such a model for quantitative purposes, it should be validated thoroughly. This study deals with the validation and calibration of the IDEFICS drift model, using an experimental single-nozzle sprayer in outdoor conditions.

MODEL DESCRIPTION

The IDEFICS drift model is a mixed 2-/3-dimensional (2D/3D) random-walk model, tracking the paths of flight of individual drops which are produced by flat fan nozzles on a conventional boom sprayer. The downwind ground deposits outside the sprayed area is calculated from the cumulative effect of a large number of drops, as well as the vertical distribution of airborne spray drops at a fixed distance downwind (Fig.1).

The model accounts for a large number of factors involved with the spraying process: field related parameters (essentially only crop height; optionally: ditch geometry, if present), sprayer related parameters (nozzle type and size, liquid pressure, boom height, distance from nozzle to downwind edge of the crop, driving speed), and atmospheric parameters (average wind speed, turbulence intensity and stability, air temperature, relative humidity).

The model uses the drop size distribution as measured by phase-doppler anemometry (PDA). Inside the spray cone below the nozzle, air is entrained. This 3D air flow distribution is estimated from PDA measurements also. In-flight evaporation of a drop is determined by air temperature and relative humidity.

Average wind direction is assumed to be perpendicular to the edge of the field. According to meteorology, average wind speed is logarithmic with height above the ground, and adjusted for crop height.

A comprehensive description of the model and its mathematical structure is given elsewhere (Holterman et al., 1997).

CALIBRATION EXPERIMENTS

To calibrate the drift model outdoor experiments with a single-nozzle sprayer carriage were carried out under varying conditions. The sprayer carriage was pulled at constant speed over a 15 m rail track (Fig.2). The track was placed perpendicular to the average wind direction. The nozzle was mounted to the carriage in such a way that the wake behind the carriage could not affect the spray below the nozzle. The spraying liquid was tap water containing a fluorescent dye (Brilliant Sulfoflavin, BSF; 3.0 g/L) and a surfactant (Agral^{TM}; 1 mL/L). Spray deposits on the ground were measured from 1.0 m upwind to 5.0 m downwind from the nozzle, using synthetic cloths (0.50x0.08 and 1.00x0.08 m^2) as collectors. Airborne spray was measured at 5 m downwind using spherical synthetic cleaning pads (diameter 0.08 m) at a spacing of 0.5 m up to 2.5 m height. After washing the collectors, BSF concentration in the extracted liquid was determined by fluorimetry.

Wind speed was recorded at 2.0 m high, relative humidity and air temperature at a height of 1.5 m. All experiments were carried out on a field of cut grass (height approx. 0.05 m). Distance to upwind obstacles was at least ten times their height, approximately.

The experiments comprised variations of boom height, nozzle type and size, liquid pressure, and driving speed, with varying average wind speeds. Each trial consisted of 1-8 passes along the same track before the cloths and pads were collected. The number of passes was chosen in accordance with the driving speed, roughly giving a similar cumulative passing time for each trial.

Table 1 shows various settings and meteorological data for the calibration trials. Each setting comprised of 2-10 replications, giving a total of 140 independent trials. Top angle of the spray cone was measured in our laboratory and sometimes differed considerably from the value given by the manufacturer. Volume median diameter (VMD) and percentage of volume consisting of drops smaller than 100 μm diameter (V100) were measured using PDA.

EXPERIMENTAL RESULTS

Spray recovery

Usually the amount of liquid sprayed cannot be recovered completely by summing all measured deposits. Firstly, part of the spray may deposit upwind from the first ground collector. This is likely in cases of large boom heights and low wind speeds. Secondly, part of the spray may evaporate, or more precisely, its water content may evaporate, leaving small 'dust' particles airborne. Such particles are unlikely to be caught by the collectors used. For the finest nozzle used in these trials, and at relatively low wind speed, this evaporative loss is estimated to be about 10% of the sprayed volume. Thirdly, the collectors are not perfectly efficient. Especially for the spherical pads to collect airborne spray this is a well-known phenomenon. Following the classical study of May and Clifford (1967), collection efficiency of spherical objects in air can be estimated to be 10-30%, depending mainly on average wind speed.

Even after correction of measured recovery for the three effects mentioned above, spray recovery on average is still lacking a significant fraction, typically being 6% of the applied volume. It is assumed that this apparently lacking part is due to UV-induced

Table 1. Experimental settings in calibration trials.

Code	Nozzle	P_{liq} [kPa]	TpAng [°]	VMD [µm]	V100 [%]	BMH [m]	Dose [l/min]	#Rep	Vdriv [m/s]	Wind [m/s]	RH [%]	T [°C]	NP
A	XR 11001	450	130	141	27.5	0.50	0.48	3	1.50	2.0-3.1	35	23-26	6
B3	XR 11003	400	125	219	12.3	0.50	1.36	3	1.50	2.7-3.9	40	10-12	5
B4	XR 11003	500	125	206	14.2	0.50	1.52	3	1.50	1.7-3.9	35	13	5
C1	XR 11004	200	120	285	6.5	0.50	1.29	3	1.50	1.8-2.3	40	20	5
C2	XR 11004	300	125	256	8.9	0.50	1.58	3	1.50	2.4-2.8	50	18-20	5
C3	XR 11004	400	125	240	10.4	0.50	1.82	3	1.50	1.7-1.8	55	19-22	5
C4	XR 11004	500	130	230	11.5	0.50	2.03	3	1.50	0.9-2.5	45	22	5
C5	XR 11004	200	120	285	6.5	0.70	1.29	2	1.50	1.7-2.8	35	21	5
C6	XR 11004	300	125	256	8.9	0.70	1.58	3	1.50	2.6-2.8	65	15	5
C7	XR 11004	400	125	240	10.4	0.70	1.82	2	1.50	3.1-3.4	60	18	5
C8	XR 11004	500	130	230	11.5	0.70	2.03	3	1.50	2.4-3.5	60	19	5
C9	XR 11004	300	125	256	8.9	0.35	1.58	3	1.50	1.4-2.5	55	25	5
C10	XR 11004	300	125	256	8.9	1.00	1.58	3	1.50	2.2-2.9	60	22	5
D	XR 11006	200	120	314	5.3	0.50	1.94	3	1.50	1.4-3.2	35	20	5
E1	XR 8008	250	80	388	3.2	0.50	2.88	3	1.50	2.1-3.5	30	21	5
F1	XR 11008	300	120	348	4.4	0.35	3.16	3	1.50	1.6-3.0	45-55	18-26	5
G1	XR 8004	300	90	268	8.0	0.50	1.58	3	1.50	1.8-2.1	35	22	5
E1	XR 8008	250	80	388	3.2	1.00	2.88	3	1.50	2.3-3.9	50	18-20	5
H2	DG 11002	300	110	291	5.7	0.70	0.79	3	1.50	2.2-2.6	45	21	5
I1	ADE 3	300	105	298	5.1	0.50	0.85	3	1.50	2.6-2.7	45	23	5
I2	ADE 3	300	105	298	5.1	0.70	0.85	3	1.50	3.4-3.6	65	19	5
J1	ID 120-02	500	100	435	2.9	0.50	0.99	3	1.50	2.2-2.3	40	20	5
J2	ID 120-02	500	100	435	2.9	0.70	0.99	2	1.50	3.8-4.4	60	19	5
K1	TD 02	500	95	399	2.8	0.50	0.97	3	1.50	2.1-2.6	40	19-25	5
K2	TD 02	500	95	399	2.8	0.70	0.97	3	1.50	2.2-6.3	50-65	17-19	5
P	TD 05	500	105	416	2.9	0.50	2.58	2	1.50	2.7-2.9	40	20	5
Q	TT 11004	150	130	465	1.9	0.50	1.12	3	1.50	1.5-1.9	55-65	22-26	5
R	ID 120-4	500	110	441	2.6	0.50	2.02	3	1.50	1.4-2.5	35	22	5
S	DG 11004	300	120	321	4.5	0.50	1.58	3	1.50	2.7-3.2	45-55	21-23	6
T	8015 SS	200	80	492	1.7	0.50	4.83	2	1.50	0.5-1.8	55-70	19	5
V1	LF 110-01	450	110	137	28.5	0.50	0.46	3	1.50	1.8-2.5	85	12	7
V2	31-03-F110	300	110	247	10.1	0.50	1.16	3	1.50	2.6-2.8	80	13	5
V3	LU 120-06S	200	120	301	6.0	0.50	1.93	3	1.50	2.8-3.0	80	13	5
STD	XR11002	300	125	184	16.0	0.50	0.79	10	1.00	0.8-5.3	65-80	15-18	5-8
H35	XR11002	300	125	184	16.0	0.35	0.79	4	1.00	2.9-3.2	60	21-23	5
H75	XR11002	300	125	184	16.0	0.75	0.79	4	1.00	2.4-5.6	60	20-24	5
H100	XR11002	300	125	184	16.0	1.00	0.79	4	1.00	2.4-3.6	55	22	5
R10	XR11002	300	125	184	16.0	0.50	0.79	2	0.10	2.3-2.4	60	19	1
R25	XR11002	300	125	184	16.0	0.50	0.79	4	0.25	1.8-3.1	45-55	25	2-3
R150	XR11002	300	125	184	16.0	0.50	0.79	3	1.50	3.1-3.4	55	19	8
XR04	XR11004	300	125	256	8.9	0.50	1.58	4	1.00	2.7-2.9	70	18	5
XR08	XR11008	300	125	348	4.4	0.50	3.16	4	1.00	1.8-3.3	65-90	11-19	6
DR2	XR11002	200	125	201	12.4	0.50	0.65	4	1.00	1.9-2.9	65	18	5
DR5	XR11002	500	130	173	20.1	0.50	1.02	3	1.00	1.9-2.7	80	12	5

Code: experimenter's code to identify trial; Nozzle: manufacturer's coding; P_{liq}: liquid pressure; TpAng: top angle of the nozzle; VMD: volume median diameter; V100: percentage of volume containing drops smaller than 100 µm diameter; BMH: boom height above crop; Dose: nozzle flow rate at given pressure, according to manufacturer; #rep: number of replications per trial; V_{driv}: driving speed; Wind: range of mean wind speeds, averaged per replication, measured at 2 m height; RH: relative humidity at 0.5 m height; T: air temperature at 2 m height; NP: number of passes before sampling.

degradation of the fluorescent dye in the time lapse between spraying and collecting the samples. The measured deposits were corrected for this estimated degradation deficit, after which comparison with simulation results could take place.

Example results

Fig.3 and 4 show examples of ground deposits for the single-nozzle experiments, using a medium-sized nozzle (XR11004 at 300 kPa) at two boom heights and at medium wind speed. With respect to reproducibility these figures represent typical outer limits for all trials. Fig.3 shows a high reproducibility between replications, while reproducibility in Fig.4. is rather poor. Though the graphs suggest deposit values at fixed points, given deposits rather are average values for the collectors used (with lengths 0.5 and 1.0 m). In fact the x-positions as used in the graphs represent the location of the midpoint of the collectors.

Included in these figures are calculated deposits using the drift model, before calibration (see next section).

COMPUTATIONAL RESULTS AND CALIBRATION

First comparison

Model calculations were done for all circumstances covered by the field tests. Calculated ground deposits were compared with experimental ground deposits. Fig.3 and 4 show calculated deposits (dotted lines) together with according experimental deposits (solid lines). Clearly the model overestimates deposits farther downwind than about 1 m from the nozzle.

Fig.5 gives an overall view calculated deposits together with measured deposits for all ground collectors in all trials. This plot shows that deposits larger than about 10% of the applied dose can be estimated well by the drift model. From 10% down to 0.1% of the applied dose the calculated deposits overestimate the actual deposits progressively, roughly up to a factor of 10 for deposits below 0.1% of the applied dose. At the same time, variance of calculated deposits increases with decreasing actual deposits.

Calibration

Obviously downwind ground deposits are highly correlated with boom height and wind speed. Defining a normalised distance X_n in which first-order effects of boom height and wind speed are accounted for, simplified the process of calibrating the simulation model. X_n is defined by:

$$X_n = \frac{x}{h_{eff}} \left(\frac{v_0}{u_{avg}} \right)^m$$

where x is the actual downwind distance from the nozzle, h_{eff} is the effective boom height, defined as the height of the boom above the midpoint of crop height, v_0 is the initial velocity of drops at the nozzle outlet, and u_{avg} is the average wind speed. Constant m is set equal to 0.3, though this value appeared not to be very critical.

The ratio of calculated and measured deposits appeared to be a very coarse function of normalised distance (Fig.7). In fact this ratio represents the factor needed to correct the calculated deposits in order to obtain the measured deposits exactly. So if this ratio could be explained as an empirical function of the various parameters involved in the spraying process, we would have obtained a calibration function to correct the calculated deposits.

It turned out that the best way to proceed was first to fit the ratios coarsely as a function of normalised distance (i.e. fitting the solid line in Fig.7), and next to use regression analysis involving the other spraying parameters to fine-tune the empirical calibration function. It appeared that this fine-tuning was rather insignificant and affected the calibration function only slightly. Fig.6 gives the comparison of calculated deposits after calibration and actual ground deposits. It clearly shows that on average the calibrated model works fine, though the observed variance roughly is still as large as before calibration.

DISCUSSION

Since variance in field trials in practical situations involving conventional boom sprayers is high, such trials can hardly be used to validate or even calibrate the drift model. The use of the single-nozzle set-up facilitated the calibration of the IDEFICS drift model considerably. However, so far calibration experiments have only been carried out on short grass, not in an actual crop. Further calibration experiments should involve crop presence also.

The calibration process as described above involved corrections for recovery losses and degradation losses, previous to the calibration process itself. Though these corrections are essential for a good description of the calibration function, they tend to obscure an independent comparison of calculated and observed deposits. Careful consideration of experimental set-up may overcome partially the need for such corrections.

The good reproducibility in the single-nozzle experiments offers the possibility to use such trials for investigating spray drift behaviour of individual nozzles under varying conditions. Since conditions are linked closely to conditions in actual pesticide applications, results of such trials can be extrapolated to actual applications with high accuracy. Especially regarding drift-reduction policies the single-nozzle trials have high potential in classifying spray nozzles with respect to driftability behaviour.

REFERENCES

H.J. Holterman, J.C. Van de Zande, H.A.J. Porskamp, J.F.M. Huijsmans. 1997. Modelling spray drift from boom sprayers. Computers and Electronics in Agriculture, 19, 1-22.

K.R. May, R. Clifford. 1967. The impaction of aerosol particles on cylinders, spheres, ribbons and discs. Ann. Occup. Hyg. 10, 83-95.

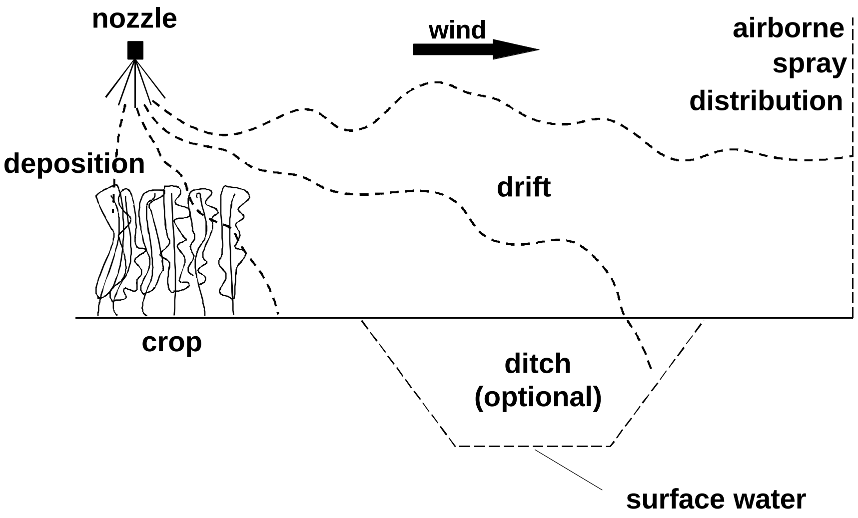

Fig. 1. Typical field lay-out for the simulation model.

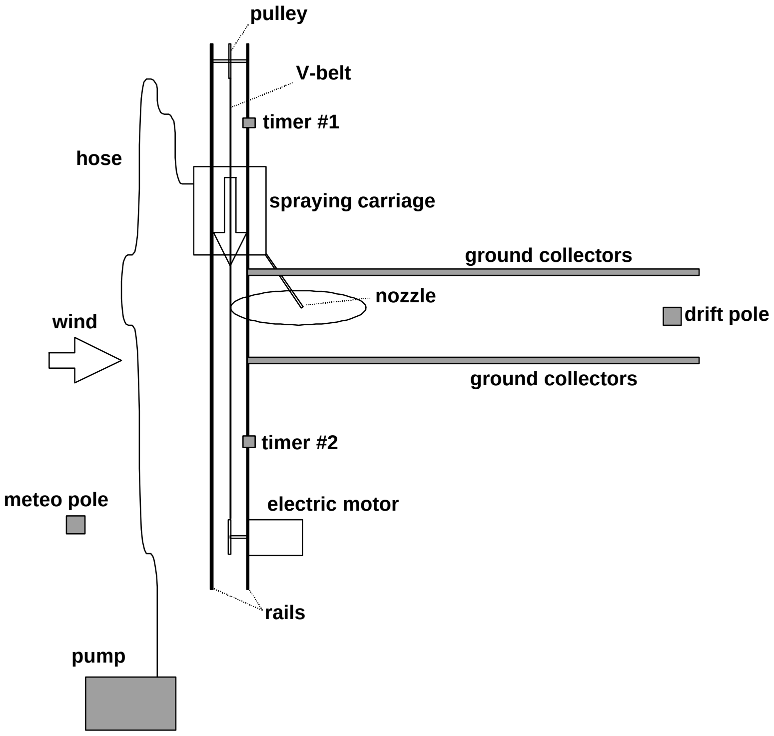

Fig. 2. Set-up of validation experiments, using a single-nozzle spraying carriage.

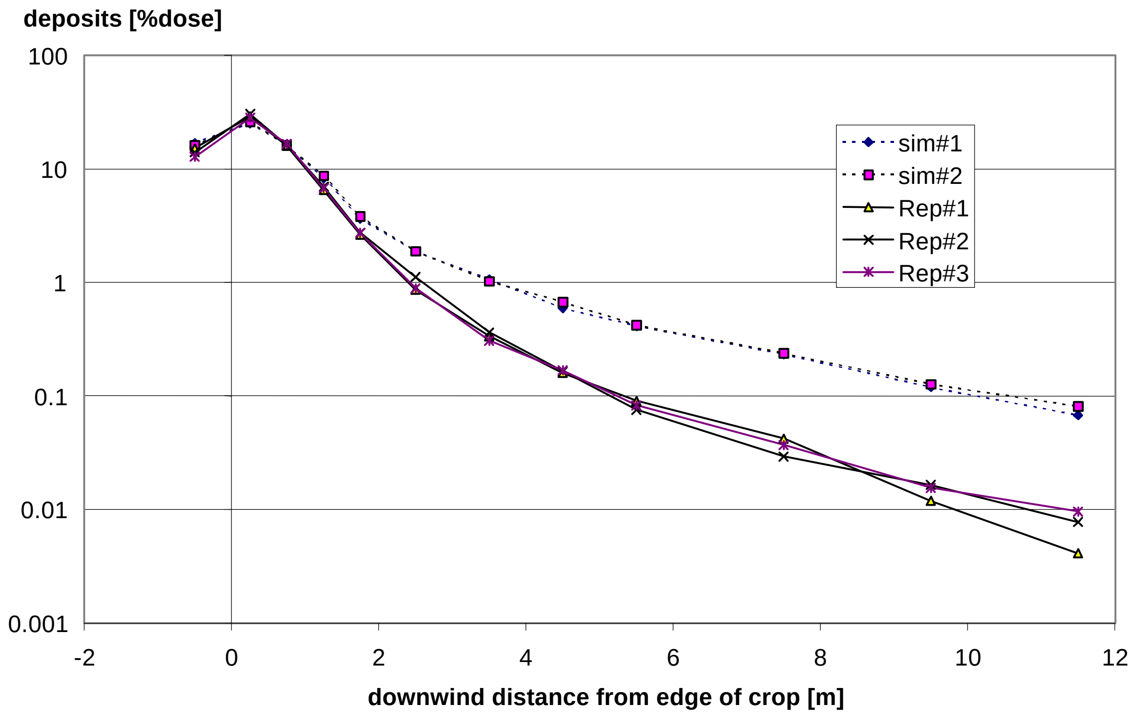

Fig. 3. Ground deposits as a function of downwind distance from nozzle (trial code C6). Three replications at boom height 0.70 m, nozzle XR11004 at 300 kPa; mean wind 2.7 m/s. Replications show high reproducibility. Dotted lines represent two corresponding simulations.

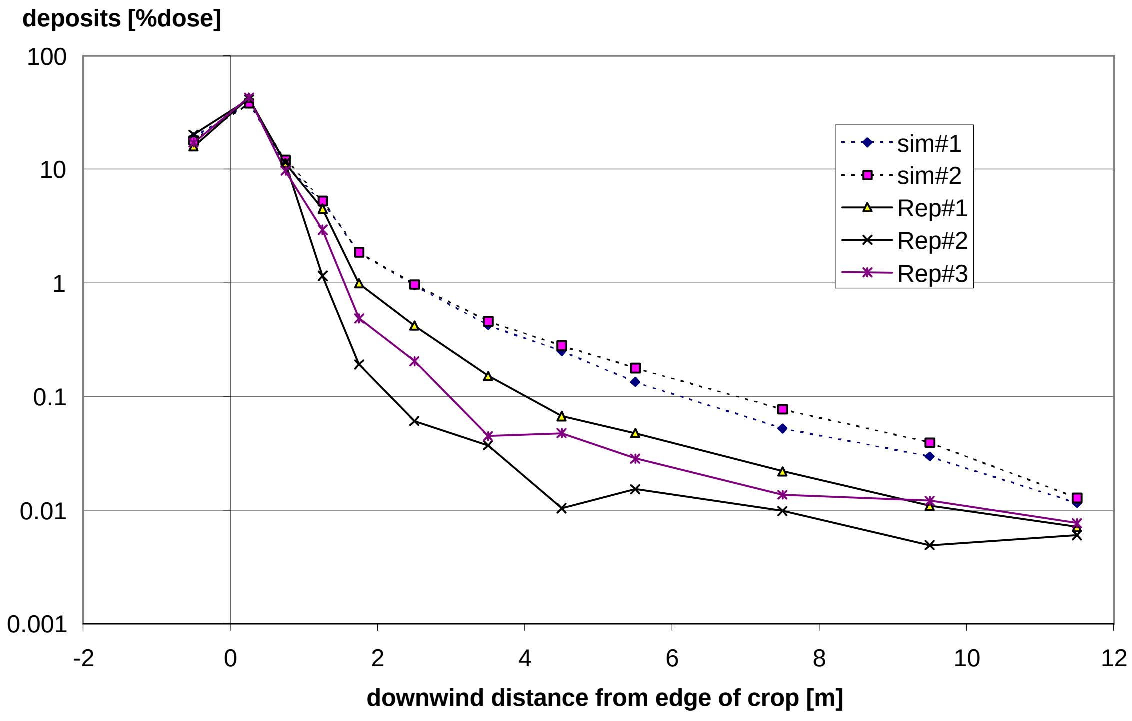

Fig. 4. Ground deposits as a function of downwind distance from nozzle (trial code C2). Three replications at boom height 0.50 m, nozzle XR11004 at 300 kPa; mean wind 2.6 m/s. Replications show relatively poor reproducibility. Dotted lines represent two corresponding simulations.

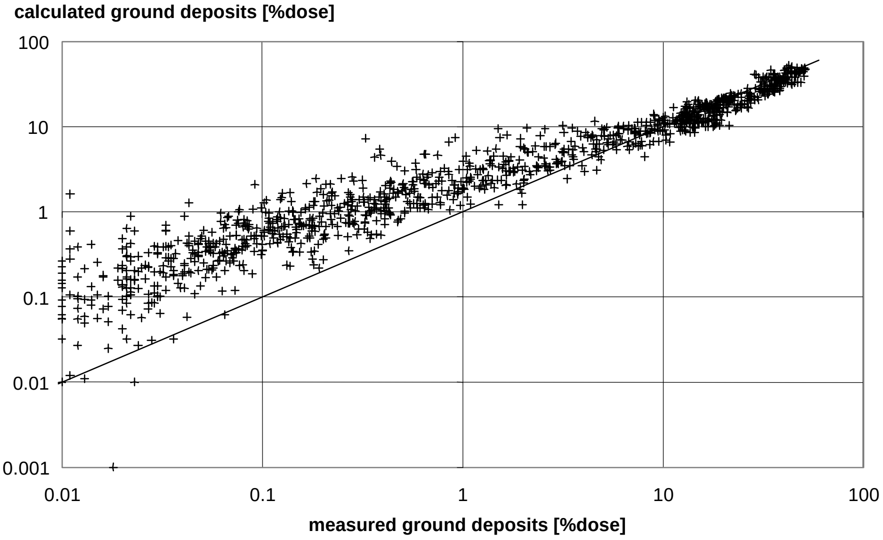

Fig. 5. Overall comparison of calculated and measured ground deposits. Measured deposits are corrected for degradation losses (see text).The solid line (y=x) shows the ideal relationship of perfectly matching values.

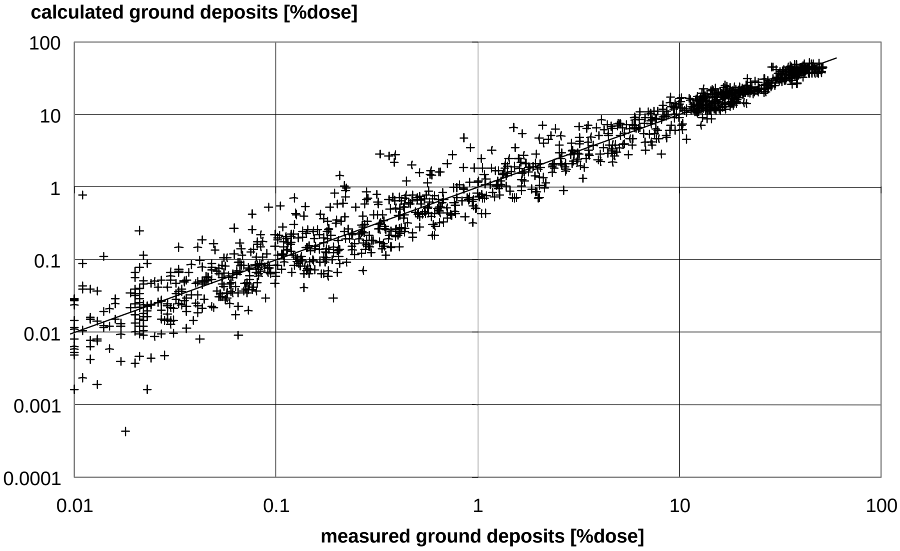

Fig. 6. Overall comparison of calculated and measured ground deposits, after calibration. Measured deposits are corrected for degradation losses (see text).The solid line (y=x) shows the ideal relationship of perfectly matching values.

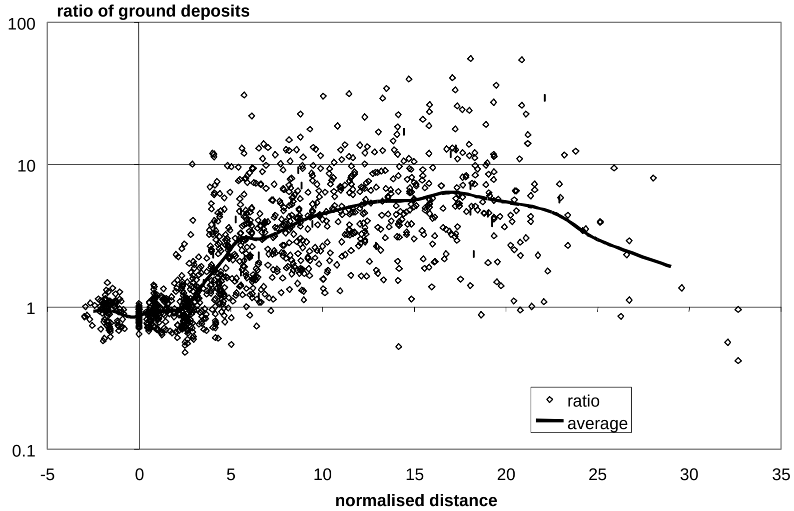

Fig. 7. Ratio of calculated and measured ground deposits, as a function of normalised distance. The solid line represents the average relationship.