RTDrift: a real time model for estimating spray drift from ground applications

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Abstract

A spray drift model called RTDrift was developed to estimate drift caused by ground sprayer machines. The sprayer was equipped with sensors measuring operational parameters namely spray pressure, boom height and movements, and geolocalization. Climatic parameters, including wind speed and direction, were measured using a 2-D ultrasonic anemometer mounted on the sprayer. The nozzles spray drop size spectra were characterized using Phase Doppler Interferometer measurements. At every successive boom position, a diffusion-advection Gaussian tilted plume model computed the spray drift deposits for each drop class taking into account evaporation. The contribution of a single nozzle was calculated by integration of the individual puffs with respect to time and summation of the contributions of individual drops classes. The overall drift generated by the sprayer machine was obtained adding the contributions of all the nozzles. Field trials were performed on a fallow field with water and on crops with pesticides in various wind conditions. The ground drift was measured at different drift distances using fluorometric methods. When comparing the results of the model with experimental measurements of deposits, the model produced realistic maps of drift deposits. Some further improvement is needed in the presence of large scale eddies.

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The model offers potential benefits for the farmer as a real time drift estimator embedded on a sprayer machine.

Keywords: *drift; Gaussian tilting plume model; pesticide application; embedded measurements*

1 Introduction

Pesticides play an important role in modern agriculture, although they can cause an undesirable pollution of the environment. In most cases, pesticides are applied by the spraying of an aqueous emulsion and/or suspension by using nozzles. As a result, part of the spread compound does not reach the target area but is transported by wind beyond the treated field. This process called the drift is a significant concern since it affects human health and environment. It can cause pesticide exposure to farm workers, children playing outside, and wildlife and its habitat, or contaminate home gardens or crops, causing illegal pesticide residues and/or plant damage (Hewitt, 2000).

Considering that the design, construction and maintenance of machinery for pesticide play a significant role when aiming at reducing adverse impacts of pesticides on human health and environment, the European Parliament approved on 22 April 2009 the proposal for a directive on machinery for pesticide application, amending Directive 2006/42/EC of 17 may 2006 on machinery (DIRECTIVE 2009/127/EC). This directive specifies that ‘the machinery should be designed and constructed to ensure that pesticide is deposited on target areas, to minimise losses to other areas and to prevent drift to the environment’.

The factors that influence drops pesticide emission to air during application result from the interaction between technical and environmental features (Gil and Sinfort, 2005). The importance of drop size spectrum is known since a long time ago. It depends on the nozzle design as well as the physical properties of the pesticide formulation and spray additives (Butler Elis and Tuck, 1999; Miller and Butler Ellis, 2000; Stainier et al., 2006a). The height of the nozzle and the forward driving speed are also operational characteristics that affect drift. The main environmental features are the wind characteristics (speed, direction and turbulence) that influence the transport, the temperature and humidity that affect the evaporation (Miller et al., 2000).

Numerous numerical models have been developed to predict spray drift. These models fall into empirical or mechanistic categories. The empirical ones are based on field measurements of spray drift. The most famous databases originate from the spray drift task force (SDTF) in the US and the Federal Biological Research Centre for Agriculture and Forestry (BBA) in Germany. The first one includes analyses of the factors affecting drift from aircraft, while the second one only concerned ground applications. Empirical models based on such databases do not take into account any physical basis for spray drift and are suited to derive large trends in the drift evolution. For example, based on multiple regression procedures, Smith et al. (2000) showed that the logarithm of the downwind distance was the most important variable to estimate drift.

Mechanistic models used in drift prediction may be divided between individual drop trajectory and Gaussian models. The first category estimates the movement and positions of individual drops under external physical forces by a Lagrangian approach (Thompson and Ley, 1983; Miller and Hadfield, 1989; Zhu et al., 1994; Holterman et al., 1997; Mokeba et al., 1997). In Miller and Hadfield (1989), the two-dimensional (2D) drop motion was considered in two phases: a first one close to the nozzle, where the trajectory is dominated by the conditions associated with drop formation and a second one where the effects of atmospheric turbulence were predicted by a ‘random-walk’ approach. Predicted total downwind drift deposits agreed well with measured values but the form of the vertical deposit distribution was less well predicted. The model IDEFICS of Holterman et al. (1997) was two-dimensional, but was 3D close to the spray nozzle, where the drop trajectory is dominated by the ejection speed. A comparison between model calculations and results of a practical field trial showed a good agreement if trials were averaged over several replications. The aerial spray prediction model AgDRIFT® embodied the computational engine found in the Lagragian model AGDISP, several features were added to improve the speed and accuracy of the predictions (Teske et al., 2002). This model is used as a regulatory tool to fulfil EPA’s spray drift data requirements for pesticide registration in the United States. More recently, the Navier-Stokes equations with a k-ε model for turbulence were coupled to a Lagrangian particle tracking model constructed in computational fluids dynamics (CFD) software (Baetens et al., 2007). The 3D steady state model was able to predict short distance drift (< 5 m).

Gaussian diffusion models are extensively used in assessing the impacts of existing sources of air pollution. These models describe the concentration field as a function of space and time due to the diffusion of an instantaneous point release. In the drift studies, they have mainly been associated with aircraft spraying activities. Such a model was developed by Woods et al. (2001) to monitor off-target drop movement of insecticide applied to a cotton crop. Craig (2004) mentioned that the Gaussian model has the advantage over Lagrangian models in that it is faster computationally and can readily provide real-time prediction over large distances (3 km). Tsai et al. (2004) chose the Gaussian dispersion FDM model because of its flexibility in defining changing meteorological, source, and size distribution input parameters. For spraying ground applications, a Gaussian model including a tilting plume approach was developed to take into account the sedimentation process of drops and was validated in wind tunnel (Stainier et al., 2006a).

The aim of this paper is the development of a model that could be easily used on sprayer machines to estimate the drift resulting from sprayer booms in movement. A Gaussian diffusion model was chosen because it presents a good compromise between accuracy and computational expenses. To take into account the differentiated behaviour of the drops spectrum, the overall nozzle contribution was calculated by summation of the contribution of individual drops diameter classes puffs. These latter were integrated over the sprayer displacement to estimate total concentration at a given receptor. The global emission was thus considered as a series of puffs over time, during which variations of wind speed and direction may occur.

2 Materials and methods

2.1 Spray deposits model

2.1.1 General principles

A Gaussian plume model called RTDrift was developed to describe the transport and the dispersion of the drops after their ejection from the nozzles (Fig. 1). Considering that the drops are mixed by atmospheric motions, including turbulence, and that a settling velocity is superimposed on these motions, a Gaussian tilting plume model was chosen to describe the particles concentration (Reible, 1999):

$$C(x,y,z,H_s)=\frac{Q_m}{2\pi\sigma_y\sigma_z U}exp\left\{\left[-\frac{y^2}{2\sigma_y^2}\right]-\left[\frac{\left\{z-\left(H_s-\frac{v_P x}{U}\right)\right\}^2}{2\sigma_z^2}\right]\right\} \quad [1]$$

with

C(x,y,z;H_s) : particles concentration at a receptor (g m^{-3}) ;

x, y, z : horizontal, transversal and vertical distances (m);

H_s : effective height of the nozzle with respect to the ground (m);

Q_m : rate of mass release from the nozzle (g s^{-1});

σ_y, σ_z : horizontal and vertical Gaussian dispersion parameters (m);

U : mean wind speed according to the x axis (m/s);

v_p : gravity settling velocity (m s^{-1}).

This model considered that advection by the mean wind was the primary mechanism for transport along wind direction while dispersion occurred in the crosswind and in the vertical direction. The mean trajectory of the drops was expected to be a straight line with a downward slope from the horizontal, the slope being conditioned by the gravity settling velocity. The model assumed that settling particles remained at the ground surface upon striking it.

The drops deposition rate q_m (g $m^{-2}s^{-1}$) (footprint) as a function of distance downwind (along-wind) was given by:

$$q_m=v_p C(x,y,0;H_s)=\frac{v_p Q_m}{2\pi\sigma_y\sigma_z U}exp\left\{\left[-\frac{y^2}{2\sigma_y^2}\right]-\left[\frac{\left(H_s-\frac{v_P x}{U}\right)^2}{2\sigma_z^2}\right]\right\} \quad [2]$$

The model assumed that there was no interaction between drops. This hypothesis was supported by the effect of the nozzle movements, which segregated drops from different sizes and drastically reduced the drop density comparatively to a static nozzle (Lebeau, 2004). It also supposed that drops were decelerated from initial speed by the drag force from static air interaction, not taking any entrained air effect into account. On basis of these hypotheses, drops produced by a nozzle at a given pressure were divided in homogeneous diameter classes that were assumed to drift independently.

To compute q_m from Eq. [2], the nozzle effective height and the gravity settling velocity were computed on a physical basis for each drop classes (§ 2.1.3). Other variables, like the rate of mass release from the nozzle, the wind speed and direction, and the nozzles trajectories were measured with sensors located on the sprayer machine (§ 2.1.4). In general, σ_y and σ_z are related to eddy diffusivities by definition (Pal Arya, 1999):

$$\sigma_y = \sqrt{\frac{2K_y x}{U}} \qquad \sigma_z = \sqrt{\frac{2K_z x}{U}} \qquad [3]$$

where K_y (m^2s^{-1}) and K_z (m^2s^{-1}) are horizontal and vertical eddy diffusivities. Considering that the small-scale motion in all large Reynolds number turbulent flows are statistically isotropic because of the energy cascade hypothesis, eddy diffusivities at the time scale of interest were not expected to depend on time and space, although they may be different in different directions. They were thus assumed to be constant in all trials and were obtained by calibration on the first trial.

2.1.2 Size distribution of the spray

Nozzle drop size distribution of the sprayed pesticide was measured for different pressures according to ISO/CD 25358 (2007) recommendations with a Phase Doppler Interferometer (PDI-300 Artium). Drops produced by a nozzle at a particular pressure were divided in 16 homogeneous diameter classes, 5 cm under the nozzle, where the liquid sheet was broken up into individual drops: < 30 µm, 30-40 µm, 40-50 µm, 50-60 µm, 60-76 µm, 76-89 µm, 89-103 µm, 103-120 µm, 120-140 µm, 140-163 µm, 163-190 µm, 190-222 µm, 222-258 µm, 258-301 µm, 301-351 µm, > 351 µm. The initial characteristic diameter was the mean value of each class d_{ni}, the subscript n referring to the 16 different classes. The drop size distribution modification according to pressure was tabulated

To take into account the effect of evaporation that modified the drop size spectrum under specific air humidity, the Amsden's (1962) equation was used to compute the lifetime t_{ln} of different drops diameters d_n:

$$t_{\ln} = \frac{d_n^2}{80\Delta T} \quad [4]$$

where ΔT (°C) is the difference of temperatures between wet and dry thermometers. On this basis, the linear reduction of the diameter versus time was tabulated to derive the drop evaporation. This assumption is based on the hypothesis that a spherical drop of radius *r* evaporates at a rate proportional to its exposed surface area as it moves *dV/dt = -k A*, with *V=(4/3)πr^3*, and the area is *A=4πr^2*. Therefore, *dr/dt = - k*.

The mean diameter of the drop during flight time is computed for every diameter and the nozzle drop spectrum is shifted downward accordingly, increasing long range drift potential.

2.1.3 Effective height and terminal velocity

Taking into account the gravitational force, including the effect of fluid buoyancy and the drag force, the second law of Newton was written as:

$$\ddot{z} + \frac{3C_D\rho_a\dot{z}^2}{4\rho_p d_n} = \frac{g(\rho_p - \rho_a)}{\rho_p} \quad [5]$$

$$\ddot{x} + \frac{3C_D \rho_a \dot{x}^2}{4\rho_p d_n} = \frac{3C_D \rho_a U^2}{4\rho_p d_n} \quad [6]$$

where ρ_p (kg m^{-3}) and ρ_a (kg m^{-3}) are respectively the densities of the particle and of the air. C_D is the drag coefficient. For small spherical particles for which the Reynolds number Re < 1,

$$C_D = \frac{24}{Re} \quad [7]$$

For larger values of Re:

$$C_D = 0.22 + \frac{24}{Re}\left[1 + 0.15\,Re^{0.6}\right] \quad [8]$$

For each drops class, the computation of H_s was performed in two stages. Firstly the abscise $x*_n$ of the mean impact point of a given class was calculated by integration of Eq. [6], taking into account [7] and [8] as a function of drop speed.

Secondly, for each class, H_s was computed by considering that the mean trajectory of a given class was a straight line with a downward slope of $tan^{-1}\left(\frac{v_p}{U}\right)$ from the horizontal (Fig. 2). H_s was thus obtained by:

$$H_s = \frac{v_p x*_n}{U}, \quad [9]$$

the terminal velocity being computed from Eq. [5]:

$$v_p = \left[\frac{4}{3}\frac{d_n g(\rho_p - \rho_a)}{C_D \rho_a}\right]^{1/2} \quad [10]$$

2.1.4 Embedded measurements and data processing

A measurement chain was installed on the sprayer machine (Fig. 3). The analogue output sensors were connected to a data acquisition system (Daqcard 6036E, National Instruments) installed in an embedded PC (CF71 Panasonic). RS-232 sensors were connected to the laptop using a PCMCIA card (NI 232/4). An acquisition program was developed on Labview (National Instruments) to record the measurements at 200 Hz in a data file. Embedded measurements were processed using MATLAB software (Mathworks).

Recorded parameters during field application were flow rate, wind speed and direction, and nozzles trajectories.

The instantaneous flow rate was measured by a factory installed turbine flow-meter which furnished a pulsed signal proportional to the applied flow. The initial drops characteristics (spectra and speed) were interpolated from PDI measurements tables at different pressures on the basis of measurements from a pressure sensor (Gems Sensors, 0 to 10 bars) fixed on the central section of the boom (P).

The wind speed and direction were measured by a 2-axis anemometer (Gill Instrument, Windsonic). The measurement frequency was 4 Hz and the range of wind speed was 0 to 60 ms^{-1}. The sensor was located at the front and 1.15 m above the sprayer tank, 3.6 m high above the ground. The measurements are linked to the sprayer coordinates system. On the basis of the sprayer trajectory, these measurements are transformed in Lambert 2008 coordinates in order to derive the absolute wind speed and direction. To take into account the wind speed decrease between the sensor height and the ground, a wind logarithmic profile was used according to:

$$U = \frac{u_*}{\kappa} \ln \frac{z}{z_0} \quad [9]$$

where u_* (m s^{-1}) is the friction velocity, κ is the von Karman constant (0.4), z_0 (m) is the roughness height (fixed at 0.09 for a fallow field, Reible, 1999) and U (m/s) is the mean wind speed at the height z (m).

The trajectory for each of the 54 nozzles was computed from boom movements' measurements according to the setup (figure 3) and method described by Ooms *et al.* (2002). Three accelerometers (Crossbow Technology, CXL04M3) were fixed on the boom to evaluate horizontal boom movements due to yaw and jolting motions (AC1 to AC3). These DC to 100 Hz accelerometers had a 500 mV/g sensitivity and ± 4g range. Two infrared distance-meters (Wenglor, HT77MGV80) with 300 to 1300 mm measuring range were located on each part of the boom (IR1 and IR2).

A GPS (Navman 3260) furnished the global position of the sprayer at 1 Hz. The GPS global coordinates (degrees-minutes-seconds) were converted into Belgian local coordinates system, Lambert 2008 (metres). The sprayer forward speed was measured by the factory installed wheel rotation sensor.

As a result of this data processing, a data file characterised the 54 nozzles wind speed and direction as well as the localisation in the field (X,Y), the emission height relative to the canopy, the flow and pressure.

2.1.5 Implementation of the model

The sprayed area was meshed using a 50 cm x 50 cm square grid. For each mesh, the time spent by the nozzles was computed and the relevant machine operating variables (Q_m, x,y) of the model were determined.

The absolute wind speed U and direction were estimated for each mesh from a 30 seconds moving average of the embedded wind data. The 30 seconds period was chosen as a rough estimate of mean time covered by a drop from its ejection from the nozzle to its impact on the ground.

The drift for every mesh was computed as the sum of the contributions from the 16 different drop classes. Fig. 4 presents an example of the spay desposits spatial distribution in percent of the nozzle output, where evaporation is token into account by a modification of the drop size spectrum. As the evaporation process doesn’t significantly affect tracer or pesticide quantity but only water, the sum of the spray deposits remains 100% . The footprint q_m in a diameter class q_{mn} was computed using Eq. 2 with a 5 by 5 cm² resolution. Thanks to this approach, estimation of the drift was obtained with a good accuracy for any drop size distribution, whatever the pressure changes or nozzle modifications.

The geo-referenced footprint was oriented in the wind direction and added to the spray application map with 50 by 50 cm² resolution. The summation of every mesh footprint resulted in a map of the repartition under the boom and the actual drift.

2.2 Field trials

Spray drift trials were performed during 2008 and 2009 on a 27 m wide, FORTIS Evolution 3300 (Tecnoma) trailed sprayer. Flat fan nozzles (AFX 110-04, Nozal) and air injection nozzles (ARX 10003, Nozal) were used with a 50 cm spacing. The applied volume varied between 200 l/ha and 300 l/ha, according to the treatment: trials were performed on a fallow field, wheat and chicory.

To quantify the drift, fluorescein sodium tracer (F6377, Sigma-Aldrich) was added to spray mixture at a concentration of 1 g/l. Drift measurements were performed according to ISO 22886 guidelines but the wind direction was not imposed perpendicular to travel direction to get contrasted situations that may happen in field application. Sampling matrix was set perpendicular to travel direction. The measurements were performed along spray track having a minimum length of 130 m. Fig. 5 presents as an example the experimental layout of the trials. Three sampling lines were placed on both sides of the spray track at 10 metres interval. For each sampling line, two samplers were placed in the treated area and off target drift was measured 0.5, 1, 2, 5, 10, 15, 20, and 30 metres from the treated area. On each sampler, two 2.5*10 cm² fibreglass samplers were maintained on ceramic tiles with rubber bands. The tiles were fixed horizontally on supports at the top of the vegetation level. Sixty fluorescence measurements were thus performed for each trial. After spraying, the samplers were quickly picked up, put in the shade in wooden boxes and sent to the laboratory for analyse. Samplers were washed using a phosphate buffer solution and analysed using a spectrofluorophotometer (RF-1501, Shimadzu).

A meteorological station (CR1000, Campbell Scientific) was located in the drift sampling area. A 25 Hz triaxial ultrasonic anemometer (USA-1, METEK) with 0 to 50 m/s range measured the wind speed, direction and turbulence at 3 m high. A hygroclip (S3, ROTRONIC) was used to measure air temperature and humidity at 2.4 m high. A second temperature sensor (LM35, National Semiconductor) was located 1.4 m high.

3 Results and discussion

Eight trials were performed on a two years period (table 1). During first year, trials 1 to 5 were performed on a 130 m long meadow track using water and fluorescent tracer. Trials 6 to 8 were performed in the field during the experimental farm pesticide application program to be in placed in realistic spray application conditions. Fluorescent tracer was mixed to the treatment spray mixture.

Fig. 6 presents of the results where the wind direction did not change more than 30° during the trial, what happened during trials 2 and 7. For each trial, two figures are given: the first one represents the drift versus the distance perpendicular to the track while the second gives the drift cartography. The mean wind direction during the trial is plotted to illustrate the wind direction in relation to the travel direction.

In the first figure, the measured drift deposits downwind for the three samplers' lines are expressed as a percentage of the application rate and are represented by asterisks. As expected, the deposits decreased drastically with downwind distances. The high variation between the measurements at a given downwind distance reflected the great heterogeneity of drift deposits, especially due to the boom movements that affect the nozzles height. The drift curves obtained by the model taking into account evaporation (mean curve, mean curve ± standard deviation) are also plotted with the experimental points. The standard deviation of the model is computed on the basis of the modelled deposits at the level of the three measurement collectors. The first trial (figure 6a) was chosen to fit eddy diffusivities K_y and K_z along *y* and *z* axes by using mean square regression. The computed values which were respectively 0.005 $m^2\ s^{-1}$ and 0.04 $m^2\ s^{-1}$ were used in further trials. K_z was found almost ten times larger than K_y as a result of the fitting. Indeed, a low K_y usually increases spray deposits variability along travel direction, what is consistent with observations. However, the quality of the model validation to this last parameter is low because of the lower sampling rate along the driving direction, making this last fitting tedious. Specific experiment should be conducted with increased sampling resolution to address this issue that is usually neglected in drift studies.

The second figure presents maps of the spray application. The localisation of the spray drift samplers is specified on the maps. The spray repartition under the sprayer boom is clearly visible (in red), most of fluctuations may be attributed to the sprayer boom movements which are amplified by the soil roughness. Some punctual problems could be identified, such as a too high flow rate (beginning of trial 3, fig. 6 b) or uncovered zones due to a small deviation between the successive sprayer trajectories because of the low GPS accuracy (trial 6, fig. 6 e). The deposits caused by the drift present large fluctuations, mainly due to the wind variations in direction and intensity. The favourable effect of air injection nozzles appears clearly with a drastic drift reduction.

The modelled curves fit correctly the field measurements. These are included in the interval of the field measurements which present a higher level of variability than the modelled deposits, probably because of spatial filtering by the Gaussian model, except for the longer range that may suffer from systematic underestimation, maybe because of 100% ground collection efficiency hypothesis. . However, difference between model and measurements are not statistically significant because of high deposits variation. This is clearly a weakness for the validation of such a model. A realistic comparison of the modelled map could only be performed with a continuous sampling of drift to have a exhaustive view of the drift pattern, what would be a huge analytical work. Spray deposits in the directly sprayed area presented some heterogeneities because of the nozzles movements.

The trials have shown that the model is mainly sensitive to the wind speed and direction. The height of emission also plays an important role; an increase of the boom height raising the level of deposits at the different downwind distances. During the fitting of turbulence parameters, the dispersion coefficient along *z* axis has proved to have more influence on the drift deposits that the dispersion coefficient along *y* axis, especially for long range. For instance, a tenfold increase of K_z coefficient form 0.005 to 0.05 for trial 1 results in 10% drift increase at 1 meter distance while at 30 meters, it resulted in a 400% drift increase. As a comparison, a similar K_y modification was negligible, in the few percent range. The issue of real time dispersion coefficient identification must be addressed to further increase model performance. Finally, the drops evaporation modelling was needed to predict accurately the long distances deposits. At short range, the effect was negligible as drops are big and sensitivity to drift is not significantly changed by evaporation. The effect was important for drop smaller than 250 µm whose diameter change affect more driftability. These smaller drops containing a big amount of tracer, the increase of transport distance has a very detrimental effect. For instance, in trial 1 at 15 m the evaporation modelling increases 4 times drift. At 30 metres, drift becomes significant while it was negligible without evaporation. It has to be pointed out that the use of actual pesticides in trials 6 to 8 did not affect significantly the model performance comparatively to the trials with water. The drop spectrum change induced by the physicochemical properties of the spray mixture may be too tenuous in these trials.

It has to be highlighted that the modelling of wind turbulence effect on drift deposits is not entirely taken into account by the eddy diffusivity. Large eddies occurring during the trials were modelled through the variations of the 30 seconds moving average wind values. The main restriction for use of the model originates when the wind direction changes continuously along the sprayer trajectory, what happened for trials 2 and 7 (figure 7) where the wind direction changed more than 30° during the experiment. This particular situation may originates from a wind vortex which result in curved flow lines, what is not consistent with the straight line assumption of the Gaussian plume, or a change between adjacent large eddies so that the embedded anemometer and the drops emitted by the nozzle could be thus in different air masses because of the distance that separates the anemometer from the nozzles. To overcome this problem, a more sophisticated treatment of the wind data should be developed in order to get a better estimation of the wind vector field at the level of the parcel from the wind measurements of the embedded anemometer.

4 Conclusions

The RTDrift model is based on a Gaussian tilted plume model, where each sprayer nozzle is considered as an instantaneous source having its own movements. Inputs of the model are the nozzle characteristics and embedded measurements, including namely a global positioning system, an ultrasonic anemometer and several sensors suited to give accurate information on the nozzle position and operation.

When comparing the results of the model with experimental measurements of deposits, the model produces realistic maps of drift deposits for various wind conditions. Further improvements of the model lie in the further processing of embedded wind measurements to derive a more representative wind speed and direction for more specific wind characteristics. The model is a sound basis for the development of a real time drift monitor compatible to realistic computational resources to be included in a spray controller because of the relevant information it may deliver to the farmer.

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Trial #	Date	Wind speed (m/s)	Temperature (°C)	Relative humidity (%)	Pressure (bars)	Volume/hectare setpoint(l/ha)	Mean boom height (m)	Field surface	Nozzle #	Nozzle type
1	26/06/2008	4.8	21	55.2	2.2	200	0.66	meadow	AFX 110-04	Flat fan
2	1/07/2008	1.2	27	50.8	2.1	200	0.8	meadow	AFX 110-04	Flat fan
3	23/07/2008	2.8	22.1	63.4	3.4	200	0.71	meadow	AFX 110-04	Flat fan
4	29/07/2008	3.5	26	57.9	1.9	200	0.63	meadow	AFX 110-04	Flat fan
5	31/07/2008	2	26.4	68.3	1.8	200	0.68	meadow	AFX 110-04	Flat fan
6	22/04/2009	3.2	14.7	63.9	5.2	300	0.76	wheat	ARX 10003	Air induction
7	30/04/2009	1	16.9	52.6	1.5	170	0.8	chicory	AFX 110-04	Flat fan
8	29/05/2009	4.8	19	33.2	5.7	250	0.71	chicory	ARX 10003	Air induction

Table 1.

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