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Initial developments in modelling emissions of plant protection products during drilling of treated seed

Clare Butler Ellis[1*], Andrew Lane[1], Christine O'Sullivan[1], Rafael Alanis[1], Paul Miller[1], Andrew Chapple[2], Lubos Vrbka[2]

[1]*Silsoe Spray Applications Unit (NIAB) Bedford, MK45 4HP, UK*
[2]*Bayer CropScience AG, Monheim 6690, Germany*

Abstract

The use of seeds treated with pesticides is generally recognised as a efficient and environmentally acceptable method of crop protection compared with spray application. However, the environmental effects of seed treatment active substances leaving the field by airborne transmission has not been considered until recently. The potential for adverse impacts of dust emissions from seed drills requires some estimates of environmental exposure to be available for risk assessments. Such assessments are generally based on predictions from a model and it is possible that the approaches which have been developed for exposures to spray drift could be adapted for risk assessment for dust.

However, there are significant differences between the droplets in a drifting spray plume and the dust generated during seed drilling which add to modelling complexity. These include the density of dust particles which vary with particle size; the amount of active ingredient associated with different particle sizes; the in-flight behaviour of particles which are not spherical; and characterizing the emission of dust from the various drilling machine types.

Exploring the effects of application practices, seed treatment processes and the environment, all of which influence both the dust characteristics and its dispersion, would require inordinate resources for field trials. Therefore, a dust drift model is being developed which will be used initially to explore some of the above mentioned variables but with a more general aim of eventually developing a regulatory acceptable model as part of a tiered approach for the registration of seed treatments. This paper explores the principal hurdles to building such a model and outlines progress to date.

Keywords: Pesticide; dust; drift model.

*Corresponding Author: clare.butler-ellis@niab.com
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1. Introduction

It is recognized that there is potential for adverse environmental effects of dust emissions from seed drills and therefore the process for gaining regulatory approval for seed treatments requires some estimates of exposure to be available in order to undertake the necessary risk assessment (EFSA, 2014). Exposure assessments for plant protection products are generally based on model predictions, either an empirical (e.g., data-based) or a mechanistic model. For example, the approaches which have been developed for non-target exposures to spray drift are based on experimental datasets in Europe (Rautmann et al., 2001), and on modelling in the USA (Hewitt, 2002). It is possible that these approaches could be adapted for risk assessment for dust exposures.

There are many variables which will influence the levels of environmental exposure: those relating to the conditions of use (the machinery, the operating conditions of the machinery, the seed rate); the environment (wind speed and direction, landscape); the treated seed (formulation components, treatment method, seed quality). While some of these can be controlled or influenced by the manufacturer of the seed treatment products, the way in which the treated seeds are drilled in practice is very variable. Consequently, for a robust risk assessment, a large amount of experimental data is required to ensure that a realistic range of exposures is achieved. The development of a mechanistic model would therefore be advantageous to reduce the amount of experimental data required and to assist with our understanding of the most important factors influencing non-target exposure.

There are some parallels between non-target exposure to dust from treated seed and to spray droplets drifting downwind during the spray application process. There have been many years of both measuring (Miller, 1993) and modeling (Teske et al., 2011) environmental concentrations resulting from spray drift, such that there are international standards for measurement (e.g., ISO 22866: ISO, 2005). There is no such standard for 'dust drift' measurement for pesticide exposure assessments and while there have been recent studies to develop appropriate techniques (EFSA, 2014) there are, as yet, insufficient data and no consensus about how measurements should be made. This will be one of the obstacles in the future for validating models of dust drift.

The dispersion downwind of dust particles is a similar process to that for spray droplets and therefore it is possible that models of spray drift could be adapted to dust drift. There are significant differences between droplets in a drifting spray plume and dust generated during seed drilling which add to modelling complexity. These include the density of dust particles which can vary with particle size, unlike conventional sprays; the varying amount of active ingredient associated with different particles and the in-flight behaviour of non-spherical particles. In addition, there are significant differences in emission route of the dust from the various drilling machine types compared with the emission of spray droplets.

A wide range of spray drift models have been developed over a number of years, including particle tracking models, computational fluid dynamics (CFD), and plume dispersion. Butler Ellis and Miller (2010) concluded that all these approaches have some value but need to be tailored to the intended use, the skill of the user and the problem that the model is aiming to address. Particle tracking models are the most flexible in speed of computation and their ability to include some complexity in the emission mechanism. CFD models can include highly complex structures and interactions but are slow to run and require significant expertise, making them less useful in a regulatory context. Plume dispersion models are valuable for large-scale (landscape) problems and are simple and quick to compute, and are often used for exposure assessments for airborne pollutants.

Devarrewaere et al. (2014) are developing a CFD model of dust release from a seed drill which has been used to compare predicted with measured air flows around the machinery.

An approach based on particle-tracking, potentially coupled to a plume dispersion model was proposed to allow some machinery and environmental parameters to be explored on both a local and landscape scale.

2. Model development

The Dust Drift model was based on the Silsoe Spray Drift Model (Butler Ellis & Miller, 2010) which was modified to include particle emission characteristics appropriate to seed drilling with a pneumatic seed drill. This was an idealized scenario rather than an attempt to model accurately a specific piece of machinery, so that the effect of release height and air flow could be investigated.

2.1 Emission of dust

The seed drill dust outlet is modelled as a round pipe, with diameter d, angled at θ to the horizontal, with the outlet at a height h above the ground. The initial velocity of the jet is V (Fig. 1 and 2)

The velocities in the air jet are described by classical jet theory (Abramovich, 1963). It is assumed that the air jet encounters no obstacle before the air velocity has dissipated – in particular it does not hit the ground. It is known that while this might reduce the amount of dust that is airborne, it could also cause a reflection of the air jet and the entrained dust particles and consequently increased levels of drift. This scenario was not considered for the first version of the model.

Dust is emitted evenly across the outlet in concentric rings. The velocity of the particles is equal to the velocity of the air in each ring, although in practice it might be expected that there are higher concentrations of dust at the edge of the exit than in the centre.

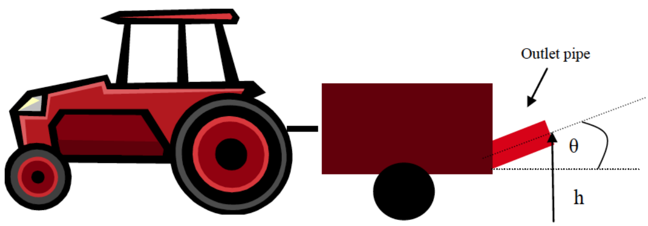

Fig 1. Schematic of modelled source – side view.

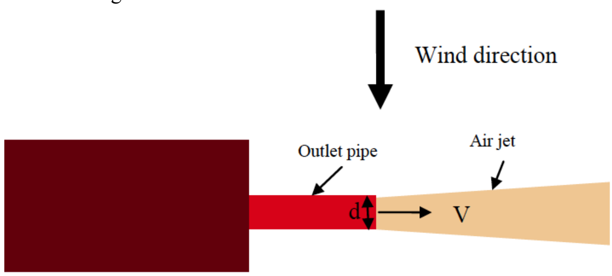

Fig. 2. Schematic of modelled source – plan view.

2.2 Transport of dust

Dust transport is considered to be either ballistic when within the air jet or a random walk when outside the air jet and is described by the same equations used in the Silsoe Spray Drift Model (Butler Ellis & Miller, 2010). The dust particles are considered to be within the jet while the air velocity is greater than the wind velocity. There is scope for improving this description, but a simple approach has been taken in the first instance.

The main equations describing the ballistic component and random walk components are described by Miller & Hadfield (1989), after Thompson & Ley (1983). An important factor in determining the motion of the droplet is the settling, or terminal, velocity of the particle which affects how quickly the particle will reach the ground. In the spray drift model, the terminal velocity of a droplet can be calculated from its diameter and density, assuming it is spherical, which is a reasonable assumption for small, drifting droplets. For a dust particle, however, this would not be a reasonable assumption and an alternative approach to determining the terminal velocity is required.

2.3 Main model input parameters

To define initial conditions for a dust particle:

- Angle of outlet to horizontal, degrees
- Jet exit velocity, m/s
- Radius of jet outlet, m
- Height of jet outlet above ground, m
- Forward speed of drill, km/h
- Initial particle velocity, m/s

To solve equations of motion:

- Surface roughness, m
- Angle of wind to forward direction, degrees
- Wind speed at 2 m above the ground, m/s
- Characteristic particle aerodynamic diameter (µm) and density (kg/m^3) of particle or terminal velocity (m/s)

To determine total exposure from all dust particles:

- Total dust output rate, g/min;
- Either: volume fraction contained within each aerodynamic diameter band and particle density within each band, or
- volume fraction contained within each terminal velocity band;
- The proportion of active ingredient contained within each diameter or terminal velocity band, mg a.s./g dust.

2.4 Model outputs

The model outputs are mg dust per m^2 ground deposit at a range of downwind distances, and mg dust per m^2 at different heights above the ground at a single distance downwind for each particle aerodynamic diameter. The intention was to take the output from the Dust Drift Model and, with some appropriate manipulation (including quantifying the active ingredient contained in different particle bands), use it as input to a plume dispersion model for landscape estimates of environmental concentrations. The Dust Drift Model therefore predicts airborne and ground deposits from only a single pass of the seed drill, and a series of such outputs would be used to create model inputs representing a drilled area for landscape scale assessment.

3. Obtaining data for model input

In order to either compare model predictions with experimental data or to conduct a meaningful risk assessment, some information about the quantity and characteristics of the emitted particles is required. For spray drift, this is usually the volume contained in each droplet size fraction, obtained using a non-intrusive measurement technique for determining in-flight droplet size distributions (*e.g.*, Tuck *et al*, 1997). The total quantity of emitted liquid is defined by the choice of nozzle and the operating conditions, and the quantity of active ingredient in each droplet is determined solely by the droplet volume. The density of droplets is also defined by the nozzle design, as air inclusions are possible, but in many cases is given by the density of the spray liquid.

For drifting dust particles, obtaining these data is much more complicated, since the shape of dust particles is highly variable and rarely spherical, the density of the particle is highly variable, and there are no well-defined methods for these measurements. The total quantity of dust emitted cannot easily be determined without interfering with the operation of the seed drill, and the quantity of active ingredient on each dust particle is likely to vary with each individual particle. Foqué et al. (2014) have undertaken some studies to characterize the dust from abraded treated seeds and obtained some useful results, but the dust was not generated by a seed drill and therefore might differ from dust produced during field operations. The detailed data ideally required as inputs to a dust drift model are probably beyond current technology, although rapid progress is likely now that effort is being applied to the problem.

A possible approach to addressing the problem of characterizing the dust particles is to focus on measurements of the terminal, or settling velocity of the particles rather than attempting to calculate this from measurements of size, structure and density that are very difficult to obtain. This terminal velocity can be expressed as an aerodynamic particle size for comparison with spray droplet distributions but can be input directly to the model without the need to determine the physical size at all. This methodology is also consistent with approaches to remove dust from the air stream using cyclones (Chapple et al., 2014), as these also operate on the basis of aerodynamic behaviour rather than physical particle size, and is consistent with the use of the ADMS plume dispersion model which has settling velocity as a primary input. Some preliminary measurements of the volume fraction of dust contained in different terminal velocity bands were made to explore the possibility of using this technique to generate model input data.

3.1 Materials and methods

The following equipment was installed in the wind tunnel at Silsoe Spray Applications Unit to determine the profile of particle terminal velocity of a dust sample subjected to the action of an air stream with constant direction and speed (Fig. 3 and 4):

- A 38 mm diameter sieve calibrated to allow the passage of particles of diameter less than or equal to 500 µm, installed in a 1 m height frame. A vibratory device was installed on the frame to allow remote starting of the discharge of the sample.

- An aluminium foil of 600 mm width placed on the floor along the wind tunnel, divided into sections of varying length. Prior to installation, initial weighing was performed for each of the sections.
- A High Volume Air Sampler (HVAS; Staplex, NY, USA) at the tunnel end to allow an estimate of non-depositing dust to be made.

Surrogate dust (bread-making 00 Flour) was used for initial experiments to test the methodology and some samples of treated seed dust were provided by Bayer CropScience (BCS). Only the portion of the dust samples that was smaller than 500 µm was used since particles > 500 µm are unlikely to drift any significant distance. It was established that the use of samples of at least 10 g per trial (divided into two sub-samples of 5 g each one, due to a lack of enough capacity of the sieve) would be required in order to obtain a satisfactory resolution of the data.
Three tests were carried out under an air stream with a constant speed of 0.5 m/s. The sections of aluminium foil were weighed again to establish the quantity of dust deposited. The sample containers and sieve were also weighed at the beginning and end of each trial to determine the percentage of sample retained on them due to the high amount of static electricity detected in the samples.

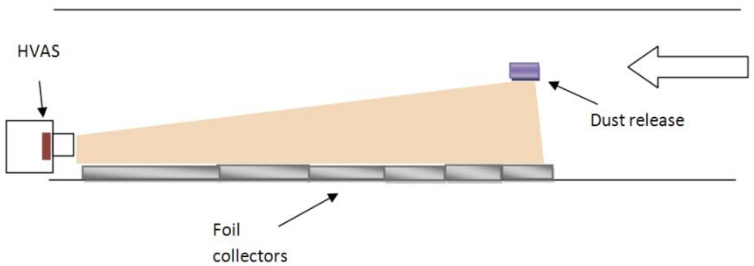

Fig. 3. Wind tunnel layout for measurement of terminal velocity or aerodynamic particle size distribution.

Fig. 4. Layout of experimental equipment showing the small sieve from which the dust is released at the top in the centre, the deposited stripe of pink dust down the centre of the foil collectors and the high volume air sampler at the end.

3.2 Results

The mean quantity of dust recovered from each foil collector, and the distances downwind are given in Table 1. The estimated terminal velocities (v_t) are based on the assumption that terminal velocities are reached instantly, and the equation:

$$v_t = \frac{h\, v_w}{d}$$

where v_t is the terminal velocity, h is the release height of the dust, v_w is the wind tunnel wind speed, and d is the distance downwind between the collector and the release point.

Table 1. Quantity of dust recovered from foil collectors in wind tunnel experiment – mean of three replicates.

Foil section	Distance from sieve (cm)	Terminal velocity, m/s	Recovered weight (g)	% sample	Std. Dev. % sample
1	-10 to + 40	>1.25	0.545	5.430	0.206
2	+ 40 to +60	0.83-1.25	1.729	17.220	0.316
3	+60 to + 80	0.63-0.83	1.257	12.521	0.149
4	+80 to +100	0.5-0.63	0.946	9.419	0.429
5	+100 to +120	0.42-0.5	0.814	8.112	0.397
6	+120 to + 170	0.29-0.42	1.437	14.320	1.002
7	+170 to + 220	0.23-0.29	0.805	8.024	0.713
8	+220 to + 320	0.16-0.23	0.732	7.295	0.615
9	+320 to +420	0.12-0.16	0.243	2.421	0.227
10	+420 to +520	0.1-0.12	0.090	0.902	0.090
Total ground deposit			8.599		
Sieve and containers			1.271	12.66	2.12
Total recovered			9.870	98.32	0.53
Initial sample weight			10.063	100.00	
Loss			0.169	1.68	0.53

Losses from the experiment were small – estimated at less than 2% of the total dust released. It is likely that the majority of this remained airborne, and the filter of the HVAS showed significant contamination with the active ingredient. This component would correspond to particles with terminal velocities less than 0.1 m/s.

The distribution of terminal velocities for the dust sample is shown in Fig. 5

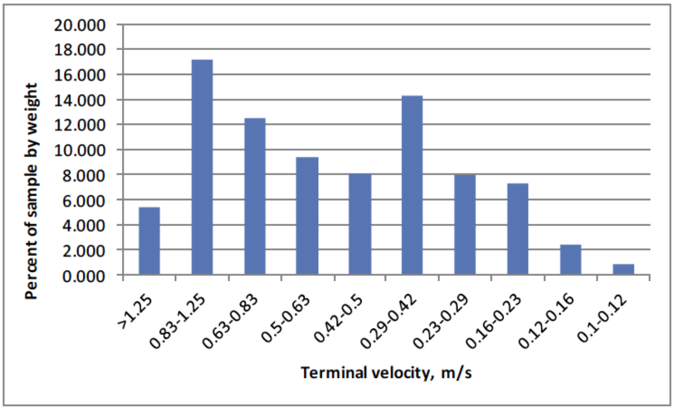

Fig. 5. Distribution of dust particles by terminal velocity.

A comparison between the terminal velocity characteristics of the dust sample and flour are shown in Fig. 6, where the quantity of dust deposited per cm linear distance is shown as a function of aerodynamic diameter, indicating that while flour can be a useful surrogate for testing methodologies, there are differences in their particle characteristics, particularly in the smaller, slower particles which were more prevalent in the dust samples than the flour. Calculation of aerodynamic diameter, *D*, is based on Stoke's Law, and is given by:

$$D = 2\left[\frac{9}{2}\frac{h\,v_w}{d}\frac{\eta}{\Delta\rho\, g}\right]^{\frac{1}{2}}$$

where $\Delta\rho$ is the density difference between particle and air, r is the droplet radius, g is acceleration due to gravity, and η is the viscosity of air.

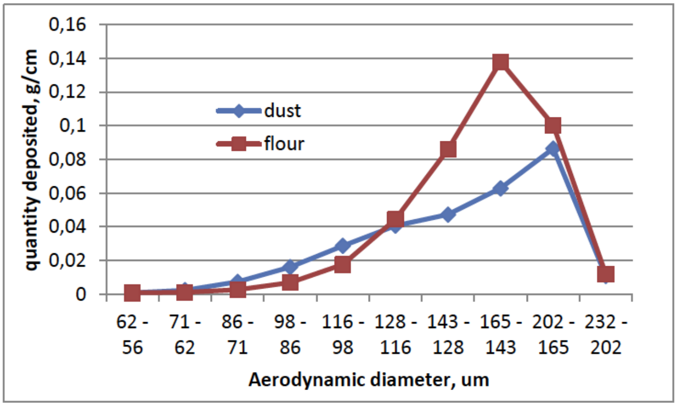

Fig. 6. Comparison of aerodynamic diameter of dust and flour particles, based on a particle density of 1000 kg/m^3.

4. Model simulations

The data shown in Fig. 5 was used as a model input, together with some arbitrary values of dust output, wind speed and machine configuration, as shown in Table 2. The predicted ground deposits are shown in Fig. 7, and the quantity of airborne dust passing through a vertical plane at 1 m downwind of the drill is shown in Fig. 8. The data behind Fig. 8 can be further processed to provide o a plume dispersion model, such as ADMS (CERC Ltd, Cambridge, UK).

Table 2. Example model input parameters.

Input parameter	**Value**
Release height	0.7 m
Angle of outlet to horizontal	20°
Air velocity at outlet	15 m/s
Radius of outlet	100 mm
Wind speed at 2 m height	3 m/s
Quantity of dust released	10 g/min
Machine speed	12 km/h

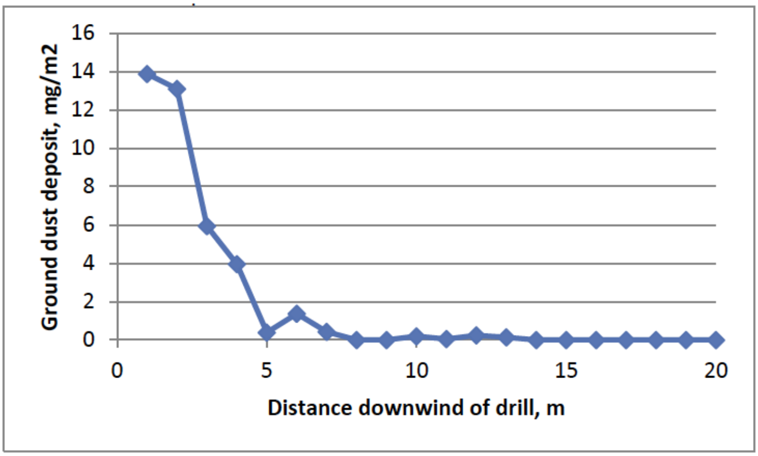

Fig. 7. Predicted ground deposit for example model run based on the input variables in Table 2 and the distribution of terminal velocities measured in wind tunnel experiments.

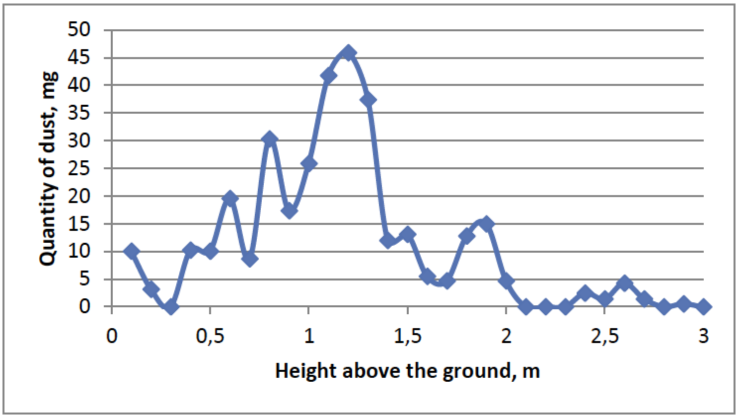

Fig. 8. Predicted airborne dust at 1 m downwind of the drill, based on the input variables in Table 2 and the distribution of terminal velocities measured in wind tunnel experiments.

The predictions are an underestimate of the potential airborne dust from the sample used in the wind tunnel measurement, since it does not take account of the component that was still airborne and collected in the HVAS.

5. Conclusions

A model has been developed to allow the influence of some variables on the drift of dust, and potential environmental concentrations of seed treatment chemicals downwind of a drilled field. The model was based on the same principles as the Silsoe spray drift model. There is a significant challenge in obtaining input data for such models relating to the characteristics and quantity of dust particles, and an approach was identified and tested for determining aerodynamic particle size of dust samples.

The technique, which used a simple experimental procedure in a wind tunnel, allowed repeatable measurements of aerodynamic particle size to be made, which were then input to the model and some predictions of environmental concentrations were made.

6. Acknowledgements

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