Silsoe Spray Applications Unit

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CONTRACT REPORT

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Study to support the introduction of mitigation from spray drift reduction into the BREAM2 model

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SUMMARY

Study to support the introduction of mitigation from spray drift reduction into the BREAM2 model

The BREAM2 model and calculator resulted in an improved model for exposure to bystanders to spray drift compared with the original BREAM model. This has resulted in a reduced level of predicted exposure for bystanders, but there is a need to reduce this further still by the introduction of mitigation.

Currently EFSA guidance for estimating bystander exposure allows maximum of 50% drift reduction based on the use of nozzles classified as 50% drift reduction or greater. This was justifiable because drift reduction classification relates to sedimenting spray drift. The basis of models of bystander dermal and inhalation exposure is airborne spray drift. In order to determine the reduction in potential bystander exposure we therefore need to quantify the reduction in airborne spray drift.

Recently, data has been obtained that will assist in establishing whether the classified drift reduction can be used directly to adjust predicted exposures, or whether an alternative approach is required. These data suggest that the reduction in airborne drift is at least as much as that for sedimenting drift, and therefore the proposed approach is likely to be simple and conservative.

The study aims to answer two questions:

1. Is the drift reduction based on a measure of ground deposits the same as the reduction in the component of airborne spray relevant to bystander exposure?
2. Can the drift reduction classification of a nozzle be a robust measure of the reduction in bystander exposure?

There is no single set of data available to allow us to evaluate the relationship between spray drift reduction, as currently determined in different European countries, and potential bystander exposure for all the possible circumstances that might arise, and taking account of all the different variables. We have therefore taken the approach of reviewing field and laboratory data, providing new laboratory data and supplementing these with model simulations. This provides an analysis that builds on current knowledge, is as broad and robust as possible and is cost-effective.

The majority of the data considered in this study show that the reduction in potential exposure of bystanders by using drift reducing nozzles is at least as great as the reduction in ground deposits at the same location downwind. Further analysis suggests that the potential exposure reduction is also greater than the reduction in drift as measured with the either the UK, DE or NL protocols.

Thus we can conclude that the drift reduction class for a given nozzle, provided that nozzle is used with the appropriate spraying conditions which include pressure and boom height, can be used to reduce the predicted exposure of residents and bystanders. This would apply to nozzles that have been classified according to the UK, NL or German protocols up to and including 90% drift reduction.

There are options for how this could be implemented in an exposure calculator, with the BREAM2 software requiring relatively modest changes.

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1. Introduction

The BREAM2 model and calculator, funded previously by Bayer (Butler Ellis *et al*, 2018) and ECPA (Butler Ellis and Kennedy, 2018) resulted in an improved model for exposure to bystanders to spray drift compared with the original BREAM model. This has resulted in a reduced level of predicted exposure for bystanders, but there is a need to reduce this further still by the introduction of mitigation.

Currently EFSA guidance for estimating bystander exposure allows maximum of 50% drift reduction based on the use of nozzles classified as 50% drift reduction or greater. This was justifiable because drift reduction classification has been developed for exposure of aquatic species in surface water bodies and therefore relates to sedimenting spray drift. The basis of models of bystander dermal and inhalation exposure such as BREAM, BREAM2 and BROWSE (Kennedy *et al*, 2012, Kennedy and Butler Ellis, 2017, Butler Ellis *et al*, 2018) is airborne spray drift, rather than sedimenting spray drift. In order to determine the reduction in potential bystander exposure we therefore need to quantify the reduction in airborne spray drift.

Recently, data has been obtained that will assist in establishing whether the classified drift reduction can be used directly to adjust predicted exposures, or whether an alternative approach is required. These data suggest that the reduction in airborne drift is at least as much as that for sedimenting drift, if not more, and therefore the proposed approach is likely to be simple and conservative.

The current BREAM2 calculator does not explicitly include drift reduction, but the EFSA calculator, based on BREAM, simply reduces the exposures by 50%. It is proposed that the same approach can be used but allowing reductions by 75 and 90% if the appropriate nozzle is selected. No changes to the model will be required if the hypothesis that airborne spray is reduced by as least as much as sedimenting spray drift is proven to be correct.

The situation is somewhat complicated by the fact that there is a number of different methods of classifying nozzles for drift reduction, depending on member state. The UK, Germany and the Netherlands are likely to produce similar results, and there is some planned work to compare the German and UK approaches in order to move towards mutual acceptance of data. The differences between the classifications is likely to raise questions by the regulators and therefore nozzles that are classified by the three different schemes will be included to make the findings as widely applicable as possible. There is also a French scheme but there are bigger differences with this because the reference nozzle used by the French scheme is much finer than the other three, and therefore the measured drift classification is higher. Some consideration of how nozzles classified by the French scheme can be included is given.

The main challenge with this study is not relating to model development, but to providing the necessary evidence that the proposed modelling approach will be robust. There is, therefore, a need to ensure that the data we use is high quality and comprehensive

There is no single set of data available to allow us to evaluate the relationship between spray drift reduction as currently determined in different European countries and potential bystander exposure for all the possible circumstances that might arise, and taking account of all the different variables. We have therefore taken the approach of reviewing field and laboratory data, providing new laboratory data and supplementing these with model simulations. This provides an analysis that builds on current knowledge, is as broad and robust as possible and is cost-effective.

The study aims to answer two questions:

3. Is the drift reduction based on a measure of ground deposits the same as the reduction in the component of airborne spray relevant to bystander exposure?
4. Can the drift reduction classification of a nozzle be a robust measure of the reduction in bystander exposure?

In attempting to answer these questions, some consideration should be given to data variability, and therefore a statistical analysis should be undertaken. Unfortunately, sufficient data are not available to do this rigorously, and more sophisticated statistical expertise would also be required. We have therefore only given a qualitative assessment of the implications of variability for measures of drift or exposure reduction.

The variability of drift measurements within a given trial are known to be relatively high and the variability of a derived measure of drift reduction, particularly for high levels of drift reduction, are higher still. This variability depends on many things, including the experimental protocol and the meteorological conditions, so it is not possible to generalise. Our judgement would be that differences of greater than 10 % would be needed to demonstrate statistical significance.

2. Objectives

- To investigate and demonstrate the effect of drift reduction on bystander exposures (direct dermal, inhalation and indirect dermal)
- To propose a simple approach to incorporating the findings into exposure models (particularly BREAM2)

3. Literature Review

3.1 Background

The hypothesis that we are exploring with the review of published data is that a drift reduction class allocated to a nozzle by one of the three main European methods (the JKI assessment in Germany, the University of Wageningen assessment in the Netherlands, the LERAP star-rating in the UK) can be applied to bystander exposure assessments without a reduction in the level of conservatism.

This is already accepted for 50% drift-reducing nozzles, but not yet accepted for 75 or 90% drift-reducing nozzles.

There has been concern expressed that the level of drift reduction measured for ground deposits might be greater than the airborne spray which is most relevant to dermal and inhalation exposure for bystanders.

This review aims to supplement the wind tunnel data being gathered specifically to address this question, and in particular, ensure that it is supported by field data.

There is little relevant data in the public domain that can be used – while there is a large database of ground deposits, there is no equivalent collation of airborne spray data.

The criteria for appropriate datasets are:

- Airborne spray up to 2.0 m height and/or bystander exposure matched with ground deposits at the same distances downwind;
- Data relating to a reference application and a drift-reducing nozzle/pressure under very similar conditions.

This will allow us to determine the actual drift reduction at different distances for ground deposits, the actual drift reduction at the same distances for airborne spray, from which we can infer bystander exposure, or for bystander exposure itself. Ideally, we will also have a drift reduction classification for the nozzle/pressure from the three different countries.

A search of literature did not identify anything new in published papers that would provide the necessary data. BREAM data cannot be used for this purpose as there was no reference treatment. However, the OBO project in the Netherlands has now been made available, and this contains some data that can be interpolated and used to explore the relationship between drift reduction measured with ground deposits and measured with airborne spray.

There is a small amount of UK field data from 2002 that includes both bystander exposure and airborne spray, as well as ground deposits, that has also been included in the analysis (Glass *et* al, 2002).

There is also a set of wind tunnel data that has been included in this review to supplement the wind tunnel experiment conducted specifically for this study. This was funded by Syngenta and the work was undertaken in 2017 (Butler Ellis *et al*, 2019). This was effectively the first wind tunnel experiment aimed at the assessment of drift reducing nozzles on potential bystander exposure, and the protocol which was used has formed the basis of the protocol used for the current study.

3.2 OBO data

The “Onderzoek Bestrijdingsmiddelen en Omwonenden” (OBO) study (Vermeulen *et al*, 2019) was a substantial piece of work undertaken in the Netherlands with the objective of determining the extent to which agricultural use of pesticides in the vicinity of homes contributes to exposure of residents to pesticides, in particular next to bulb fields.

As such, it focused very much on monitoring real exposures, rather than validating exposure models, and therefore much of the data obtained is not relevant to the objectives of this study, i.e. identifying the reduction in the regulatory assessment of exposure that might result from the use of drift-reducing technology. However, as part of the project, a useful set of experiments was conducted that can be used to explore the relationship between drift reduction and bystander exposure under field conditions.

These spray drift experiments are described in Chapter 5 of the OBO report. There is one set of data that meets most of the criteria set out above. This experiment is described in section 5.1.3.3 of the OBO report and the main features are summarised below:

- A reference treatment that is consistent with the NL reference treatment for drift reduction measurement;
- A drift-reducing treatment that is classified in the NL as 90%;

- Airborne spray measurements up to 2 m above the ground;
- Ground deposit measurement.

The drift-reducing nozzle chosen for the experiments (Agrotop XLTD 110 04 at 3.0 bar) has no drift-reduction classification in either Germany or the UK, which would have been preferable, but the data are still relevant and valuable.

Additional data relating to inhalation exposure of airborne spray, obtained with active collectors (suction samplers) was also obtained, which is also of value.

There is a slight difficulty in that the airborne spray measurements were not made at the same distance downwind as the ground deposit measurements – ground deposits were averaged over a distance of several metres, and the airborne spray was measured at a point at the furthest of these distances, rather than in the centre which would have been more useful for our purposes. However, because data were obtained at a sufficient number of distances downwind for both airborne and ground deposits, we can interpolate the data to determine the spray drift for both airborne and ground deposits at the same location.

Three tables in the OBO report are used to analyse for drift reduction: Table 5.6 which provides ground deposit data for the reference and drift-reduction measurement; Table 5.8 which provides airborne spray data relevant to dermal exposure; Table 5.9 which provides active airborne (suction samplers) data relevant to inhalation exposure.

The data includes measurements made over both bare soil and an onion crop (as a surrogate for a bulb crop which has a similar morphology). The current EU exposure assessment for residents and bystanders relates to bare soil or short vegetation, where the boom height is not raised to take account of crop height. The bare soil data is therefore the most useful for our purposes, but the data relating to the onion crop has also been analysed as it will be helpful to know if the same bystander exposure reduction is likely to occur over a crop as for bare soil.

The report does not make the raw data available – only mean values are published. This means it is not possible to assess the statistical significance of any differences.

Data analysis

At each distance downwind, an average percentage drift-reduction (DR) for ground deposits was calculated:

$DR = 100\ (1 - D/D_{ref})$

where D is a measure of drift (in this case, the quantity of ground deposit), and D_{ref} is the same measure for the reference system. This is shown in Table 3.1. It can be seen that the absolute level of ground deposit of drift is substantially higher over the crop than over bare soil. This would be expected because of the higher boom height above the ground when a crop is present, combined with a relatively low-density crop which will not provide much filtering of drifting spray. This result would not necessarily be expected to be the same for other crops, or even other configurations/growth stages of the same crop.

For both bare soil and crop, drift reduction reduces slightly with distance downwind, and in field conditions over bare soil is also not quite the 90% that is the official classification. This is unsurprising since the conditions for a field experiment cannot be controlled in the same way as in a wind tunnel or using a mathematical model (which is one of the ways in which the NL classification can be made) and therefore we would not expect a field experiment to deliver the same level of repeatability.

Table 3.1. Drift reduction calculated from OBO report table 5.6 for a 90% drift-reducing nozzle spraying over bare soil and an onion crop, based on ground deposits.

Distance downwind, m	Drift, % of applied spray volume per unit area						
	XR11004		XLTD11004			drift reduction, %	
	bare soil	onion	bare soil	onion		bare soil	onion
1-5	1.3	7	0.14	0.44		89.2	93.7
5-10	0.26	0.73	0.038	0.075		85.4	89.7
10-15	0.15	0.3	0.02	0.032		86.7	89.3
1-15	0.7	3.3	0.08	0.23		88.6	93.0
15-25	0.061	0.14	0.009	0.011		85.2	92.1
25-50	0.025	0.048	<0.005	<0.01			
Mean over 1 – 25 m						86.6	91.2
Mean over 5 – 25 m						85.8	90.4

Table 3.2 shows similar data for airborne spray determined at distances between 5 and 25 m downwind, with the average quantity over 0 – 1 m above ground representing exposure of a child, and over 0 – 2 m above ground representing exposure of an adult.

Table 3.2. Potential exposure reduction calculated from OBO report table 5.8 for a 90% drift-reducing nozzle spraying over bare soil and an onion crop, based on airborne spray.

	distance downwind, m	Drift, % of applied spray volume per unit area					
		XR11004		XLTD11004		Potential exposure reduction, %	
		Child (0-1 m)	Adult (0-2 m)	Child (0-1 m)	Adult (0-2 m)	Child (0-1 m)	Adult (0-2 m)
bare soil	5	1.642	1.441	0.214	0.18	87.0	87.5
	10	1.172	1.123	0.142	0.129	87.9	88.5
	15	0.792	0.789	0.134	0.118	83.1	85.0
	25	0.521	0.536	0.079	0.075	84.8	86.0
Mean 5 - 25 m		1.0318	0.9723	0.1423	0.1255	85.7	86.8
onion	5	4.634	3.953	1.093	0.957	76.4	75.8
	10	2.426	2.276	0.33	0.323	86.4	85.8
	15	1.912	1.879	0.228	0.248	88.1	86.8
	25	1.551	1.633	0.188	0.186	87.9	88.6
Mean 5 - 25 m		2.6308	2.4353	0.4598	0.4285	84.7	84.3

The average reduction in airborne drift for adult and child over bare soil is very similar to that calculated for ground deposits. The airborne drift reduction over the onion crop is slightly lower than for bare ground, and noticeably lower than for ground deposits over a crop. The drift reduction at 5 m downwind when a crop is present appears to be relatively low and also to increase with distance.

Without having the raw data available, it is not possible to identify whether this is a significant result or not.

Table 3.3 shows the reduction in airborne spray drift as measured by active samplers, which might be representative of inhalation exposure. The drift reduction is greater than that measured by ground deposits.

Table 3.3. Reduction in drift determined from active suction samplers, based on data in OBO report Table 5.9

		Drift reduction, %	
	distance downwind, m	Child (0-1 m)	Adult (0-2 m)
bare soil	5	90.8	90.6
	15	90.4	90.4
Onion	5	88.7	87.8
	15	87.6	87.4

Further analysis of the data was undertaken to help our understanding of the relationship between drift reduction determined from ground deposits and drift reduction determined from airborne spray. For each dataset, a power law was fitted and used to determine drift at distances downwind between 2 and 20 m (which defines the range of distances available in the BREAM and BROWSE models). Drift reduction was calculated over this distance range for ground and the different measures of airborne spray (Table 3.4). Where a range of distances were given for the measurement of ground deposit, the midpoint was used.

Table 3.4. Drift reduction at specific locations downwind, based on a power law curve fitted to experimental data

	Drift reduction, %				
Bare ground	ground	airborne 0-1	airborne 0-2	Inhalation 0-1	Inhalation 0-2
2	90.1	89.2	89.9	94.3	94.3
4	88.5	87.9	88.7	92.6	92.5
6	87.5	87.1	87.9	91.4	91.2
8	86.7	86.5	87.3	90.4	90.2
10	86.0	86.0	86.8	89.5	89.3
12	85.5	85.5	86.4	88.8	88.5
14	85.0	85.2	86.1	88.1	87.8
16	84.6	84.8	85.8	87.5	87.1
18	84.2	84.6	85.5	86.9	86.5
20	83.8	84.3	85.2	86.4	86.0
Mean 2 – 20 m	86.2	86.1	87.0	89.6	89.3

Onion	ground	airborne 0-1	airborne 0-2	Inhalation 0-1	Inhalation 0-2
2	94.6	81.7	80.0	88.1	87.1
4	93.0	82.7	81.5	88.2	87.4
6	91.8	83.2	82.3	88.3	87.6
8	90.9	83.5	82.9	88.3	87.7
10	90.1	83.8	83.3	88.4	87.8
12	89.4	84.0	83.6	88.4	87.9
14	88.8	84.2	83.9	88.4	88.0
16	88.2	84.4	84.1	88.4	88.1
18	87.6	84.5	84.3	88.5	88.1
20	87.1	84.6	84.5	88.5	88.2
Mean 2 – 20 m	90.1	83.7	83.0	88.3	87.8

Table 3.4 shows that, when spraying over bare ground, the drift reduction for potential dermal or inhalation exposure is greater or equal to the drift reduction determined from ground deposits from around 10 m downwind and greater. The differences are small across the whole range of 2 to 20 m, and would be likely to be much less than would be needed to demonstrate statistically significant differences although the raw data would be needed to establish this. Therefore there is no loss of conservatism in the exposure assessment if we take the drift reduction measured by ground deposits and apply this to all the exposure routes for residents and bystanders.

This is shown in Figure 3.1, where the correlation between ground and airborne spray drift reduction is plotted. The higher levels of drift reduction relate to shorter downwind distances. It can be seen that the potential exposure reduction is lower for a child than for an adult and increases with distance. This suggests that combining drift reduction with no-spray zones would not lead to a reduction in the level of conservatism in the exposure assessment.

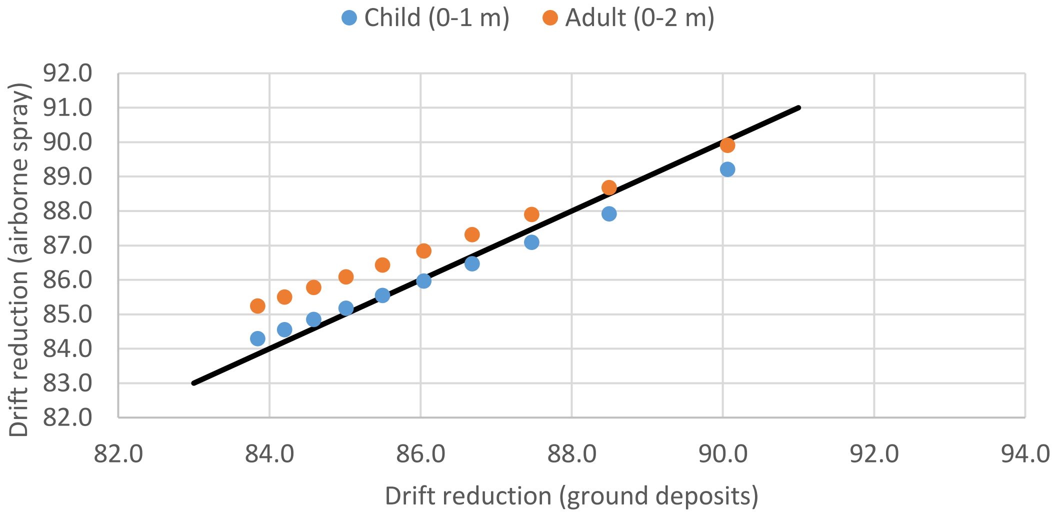

Figure 3.1. Correlation between reduction in airborne spray and reduction in ground deposits when spraying over bare soil, based on curves fitted to experimental data.

Figure 3.2 shows the reduction in airborne spray from spraying over an onion crop correlated with the ground deposits measured from spraying over bare soil. This demonstrates that the drift reduction over a crop seems to be lower than that measured when spraying over bare soil. The maximum difference is of the order of 10% (i.e. at 2 m downwind, the drift reduction from ground deposits was 90%, whereas for an adult, the reduction in potential exposure was 80%). However, the lack of raw data for analysis means that we cannot be sure the significance of this. It is anticipated that this reduction would be difficult to prove as significant, and on average, over the 2 – 20 m distance range, a reasonable assumption would be of no significant difference between the drift reduction measured by ground deposits and the drift reduction in airborne spray. Further consideration of the possible impact of a crop will be given in the modelling part of the study, section 5.

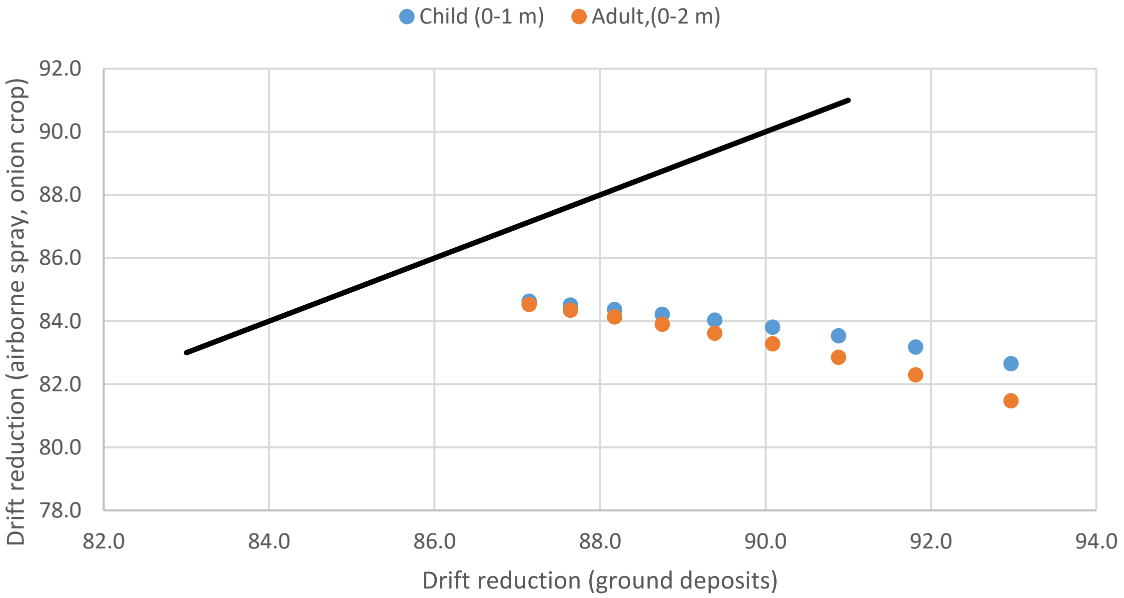

Figure 3.2. Correlation between reduction in airborne spray and reduction in ground deposits when spraying over an onion crop, based on curves fitted to experimental data.

3.3 Glass *et al* data

Glass *et al* (2002) undertook a much smaller experiment to measure drift using a reference condition and a 75% drift-reducing nozzle. Drift was measured with a range of different collectors, including ground collectors (petri dishes and laths) airborne spray (lines) and bystanders. It is therefore possible to determine drift reduction from the different collectors and again compare those relevant to airborne spray with those relevant to ground deposits. The ground conditions (i.e. crop, bare soil) were not explicitly defined in the report but it is believed that these experiments were conducted over cut grass, both in the sprayed area and downwind in the drift measurement area.

The data was selected to ensure that only runs within a narrow range of wind speeds was included, and the extremes were eliminated. This makes the data more consistent with the approach taken in the OBO report, where a relatively narrow range of wind conditions were obtained, and conditions were similar for both reference and drift reducing runs.

Table 3.5 shows the analysis, with average drift reduction measured with the different collector types compared.

Table 3.5. Drift reduction determined from a subset of data from Glass et al (2010) for four different collector types

Reference nozzle		1 m				5 m			6 m
Run	Wind speed, m/s	Petri	Lath	Bystander	Airline	Petri	Bystander	Airline	Lath
R02-08	2.4	8.98	13.14	0.198	0.0047	0.31	0.04	0.0017	0.36
R02-12	3.1	3.41	9.86	0.257	0.0124	0.29	0.072	0.0059	0.61
R02-13	3.5	4.64	4.71	0.17	0.0035	0.38	0.099	0.0039	0.74
R02-18	2.9	6.84	12.1	0.204	0.0086	0.44	0.067	0.0048	0.82
Mean	**3.0**	**5.97**	**9.95**	**0.207**	**0.0073**	**0.36**	**0.070**	**0.0041**	**0.63**
sd	0.5	2.46	3.75	0.04	0.004	0.07	0.024	0.002	0.2
75% drift reduction nozzle		1 m				5 m			6 m
	Wind speed, m/s	Petri	Lath	Bystander	Airline	Petri	Bystander	Airline	Lath
R02-04	2.2	19.98	9.80	0.162	0.0007	0.15	0.018	0.0004	0.06
R02-05	2.4	15.46	14.85	0.078		0.3	0.013		0.15
R02-10	3.4	0.47	1.25	0.035	0.001	0.12	0.012	0.0007	0.22
R02-20	3	5.18	6.75	0.061	0.0015	0.06	0.009	0.0002	0.07
Mean	**3.2**	**2.83**	**4.00**	**0.048**	**0.0013**	**0.09**	**0.011**	**0.0005**	**0.15**
sd	0.6	9.0	5.69	0.055	0.0004	0.10	0.004	0.0003	0.08
Drift reduction, %		**52.7**	**59.8**	**76.8**	**82.9**	**74.6**	**84.9**	**89.0**	**77.1**

At 1 m downwind, the drift reduction based on ground deposit is clearly much lower than the 75% indicated by the drift classification of the nozzle. 1 m is too close to the treated area to represent drift – this would have included a component of swath shift due to the prevailing wind which will be unaffected by drift reducing nozzles. This is a good illustration of the limits for applying drift reduction – in the UK it is not recommended below 2.0 m. However, both airborne spray and potential bystander dermal exposure are reduced by around 75% or more, probably because the airborne spray is much less affected by the swath shift. At 5 and 6 m, the drift reduction measured with the two ground deposit collectors – Petri dishes and laths - have the lowest drift reduction and the bystander exposure and airborne spray collectors show significantly higher levels of drift reduction. While this is only a small dataset, it supports the conclusion from the OBO report that airborne spray drift reduction is no lower than that measured from ground deposits and, moreover, that this also translates directly into a reduction in potential bystander dermal exposure.

Because these data include individual runs, rather than just mean values, it is possible to give some consideration of the variability of field measurements of drift reduction. The standard deviation can be greater than 100% of the mean value; the coefficient of variation is greater for the drift-reducing nozzle than the reference nozzle, and a typical CV could be in the range 20 – 50%. When calculating drift reduction, this variability will be magnified so that it is clear that differences of a few percent will not be significant.

3.4 Syngenta-funded wind tunnel study

The final set of data that we consider in this review is wind tunnel data (O'Sullivan *et al*, 2019) that is complementary to the experiment that was conducted as part of this study. It uses different nozzles, with a range of levels of drift reduction from 75% upwards and its particular value to this study is that it used real tank mixes including two different formulation types, an EC and an SC as well as a typical reference liquid.

Table 3.6 shows the calculated drift reduction in total airborne spray, determined from the vertical profile up to 2 m height. It can be seen that the formulations themselves give drift reduction of more than 50% when sprayed through the reference nozzle. However, formulation has a much smaller effect when sprayed through drift-reducing nozzles.

Table 3.6 Percentage of airborne spray reduction, compared with the reference nozzle spraying 0.1% Tween, for the nozzles and products tested, averaged over 0 -2 m height.

	distance downwind, m	**Reference nozzle**	**ID3-05; 3 bar**	**TTI-05; 2 bar**	**GA 03; 1.5 bar**
Tween 20	3 m		94.6	97.4	84.6
	4 m		94.2	96.5	81.4
	5 m		95.2	95.4	83.9
EC	3 m	53.7	96.7	96.5	94.1
	4 m	54.4	96.8	94.8	94.6
	5 m	58.7	96.5	96.7	96.1
SC	3 m	46.6	97.4	97.8	93.8
	4 m	51.9	97.9	97.0	93.5
	5 m	66.9	98.5	98.2	96.0

The data in Table 3.6 are plotted against the equivalent drift reduction determined using the horizontal profile (i.e. the lowest collecting line), which is the wind tunnel equivalent to a measure of ground deposit, used in the UK protocol for determining drift reduction. This is shown in Figure 3.3 There is only a small difference in drift reduction between horizontal and vertical profiles, with a slightly lower mean level of drift reduction determined from the vertical profile, but this would not be statistically significant.

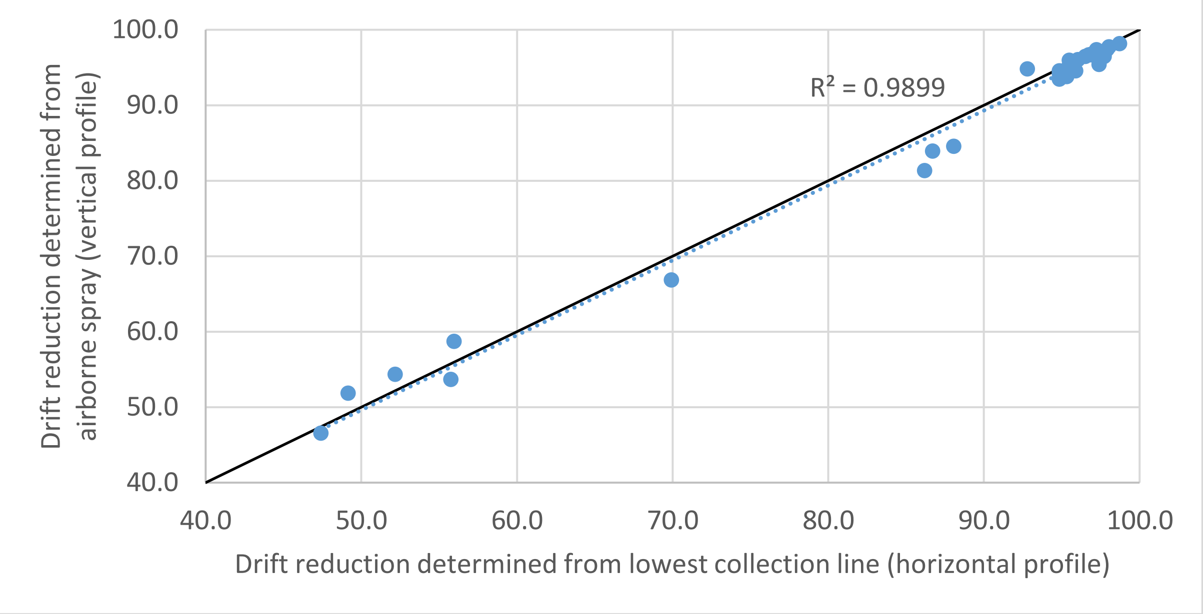

Figure 3.3. Correlation between drift reduction measured using the lowest collecting line from the horizontal profile and the drift reduction calculated from the total airborne spray, at distances of 3, 4 and 5 m downwind and all liquids and nozzles. The black line shows the 1:1 ratio; the dotted blue line shows the calculated regression line.

The importance of this result is that it shows the use of commercial formulated products, which are known to influence droplet size and drift, does not affect the relationship between drift reduction relevant to ground deposits and drift reduction relevant to bystanders.

3.5 Conclusions

Three sets of data have been reviewed with the aim of establishing the reduction in bystander exposure that might occur in practice in the field when using drift-reducing nozzles.

The largest, and most comprehensive, dataset has come from the recent OBO report. This work was undertaken to obtain data that is specifically relevant to residents and bystanders, and a bespoke experiment was conducted at the University of Wageningen that provides highly relevant data for both airborne spray and ground deposits with a reference and a 90% drift-reducing nozzle. It included spraying over both bare ground and a crop.

An older, and smaller dataset was also reviewed (Glass *et al*, 2002) which had the benefit of including bystanders as well as airborne spray and ground deposit measurements for a reference and a 75% drift-reducing nozzle.

A third set of data obtained in the SSAU wind tunnel (O'Sullivan *et al,* 2019) was also included because it included commercially-available formulated products which represent the majority of the types of tank mixes used in practice.

The OBO data showed that potential bystander exposure reduction, based on airborne spray, is likely to be very similar to the drift reduction obtained from measurements of ground deposits. Because of the lack of information on the variability of the measurements, it is not possible to explore the statistical significance of these findings, and therefore we can conclude that there is no evidence to suggest that, when spraying over bare ground, the exposure reduction is less than the drift reduction.

Further data with a wider range of crops is needed to establish whether this is also true for spraying over crops – the data in the OBO report suggest a smaller reduction when spraying over a crop.

The other two datasets support the conclusion that when spraying over bare ground or short vegetation, the reduction in bystander exposure is similar to the reduction in ground deposits. The Glass *et a*l (2002) data showed that exposure reduction based on bystanders is larger than the drift reduction from ground deposits, and the wind tunnel data (O'Sullivan *et al*, 2019) showing that airborne spray drift reduction is the same as the drift reduction measured with the standard wind tunnel protocol with typical formulation types.

4. Wind tunnel measurements

4.1 Introduction

There are different laboratory-based approaches for determining drift reduction of nozzles or spraying equipment in different European states. The UK, Germany and France use wind tunnel measurements of drift from an individual nozzle. Measurement protocols and calculation methods differ between the three, with France and the UK using the variation of drift with downwind distance (a horizontal profile) and Germany using the variation of drift with height above ground (a vertical profile) at a single downwind distance.

The NL uses a different approach –a combination of spray characterisation with a model simulation of sedimenting drift as a function of distance downwind – but this would be expected to be strongly correlated with a wind tunnel measurement of drift at different downwind distances.

All four countries also accept field trials as a basis for determining drift reduction, which is necessary when equipment is not amenable to small-scale laboratory experiments. Butler Ellis *et al* (2017) showed that drift reduction measured in the SSAU wind tunnel using a horizontal profile was correlated with field measurements of drift reduction using ground deposits. This study also showed that using the UK wind tunnel at SSAU, the drift reduction determined with a horizontal profile was very similar to the drift reduction determined with a vertical profile.

Thus while there are differences between the different methods, there are strong scientific reasons to support the assertion that they will give the same levels of drift reduction for the same test and reference nozzle conditions.

The greatest difference between the schemes is the reference nozzle that is used. Each of the UK, German, Dutch and French schemes uses a different nozzle, so that even if the measurement protocols gave identical data, the calculated drift reduction would be different. However, the differences between the German, Dutch and UK reference nozzles are relatively small, and in a recent field study to evaluate drift reduction of spraying equipment, the Dutch reference nozzle was used as an acceptable alternative to the UK reference nozzle (Stallinga *et al*, 2018). This study showed that the drift reduction measured according to the UK and NL field protocols were similar, but drift reduction from French protocol was significantly different from that for the UK and NL. It should be noted that the UK has recently changed its reference nozzle to one which is similar but potentially slightly closer to the German and Dutch reference nozzles (Butler Ellis *et al*, 2020).

As we believe that the UK, NL and German systems are similar, we could take the UK's LERAP star rating measurement protocol and use only this for the comparison. There is a danger, however, that where the drift reduction classification was obtained in a different country with a different reference nozzle, there may be a reluctance for regulators to accept the applicability of the findings. We have therefore made measurements with all three reference nozzles and use them to estimate drift reduction according to a calculation method as close as possible to that used in the three different countries. Because there are significant differences with the French reference condition, we have not included this in the measurements and analysis.

Because drift reduction classes (e.g. 50, 75 and 90%) are used for nozzles and equipment, (international standards, 2006) rather than the actual measured drift reduction, which is not made publicly available, the drift reduction for any given nozzle could be anywhere within that class, and only when close to a class boundary could it be given a different classification according to the different countries' methods. it is therefore important to establish the relationship between bystander exposure reduction and *actual* drift reduction, rather than the drift reduction class, as this is a more meaningful parameter with a greater resolution.

4.2 Measurement of potential bystander exposure reduction

The same collectors can be used in the wind tunnel as those that have been used in field studies to capture airborne spray drift. The distribution of airborne spray with height above the ground is significantly different from that which occurs in the field because there is very little turbulence within the wind tunnel compared with an atmospheric flow, and it is turbulence that causes the spray plume to disperse vertically. However, the total quantity of spray that is detrained from the nozzle is expected to be similar to that which would occur in the field under similar conditions. We can therefore compare airborne spray from a drift-reducing nozzle with airborne spray from a reference nozzle to determine the potential bystander exposure reduction.

4.3 Objectives of experiment

- Identify a set of nozzles with which to conduct drift measurements in the wind tunnel. This included reference nozzles for UK, NL and Germany and nozzles that are classified in UK, NL and Germany at approximately 50%, 75% and 90% levels
- Make measurements of airborne spray drift between 0 and 2 m height above floor at 2 and 5 m downwind, and sedimenting drift.
- Analyse the data to determine actual drift reduction using the three different approaches and potential bystander exposure for drift-reducing nozzles.

4.3 Materials and Methods

4.3.1 Nozzles

The reference nozzles from the UK, Netherlands and Germany were included in tests (Table 4.1). The Lechler ID3 nozzle, ID-120-03 has been classified in the three countries at 50 to 90% drift reduction, depending on the operating pressure (Table 4.2). This nozzle was therefore also used in tests to determine both the potential drift reduction for each of the three countries and the potential bystander exposure.

Table 4.1. Reference nozzles used in UK, Netherlands and Germany.

Manufacturer	Nozzle	Pressure, bar	Country Reference
Teejet	TP110-03 SS	3.0	UK
Teejet	XR110-04	3.0	Netherlands
Lurmark	F110-03 SS (BCPC No.11)	3.0	Germany

Table 4.2. Drift Reduction class for each country for the Lechler ID3 nozzle ID-120-03

	2.0 bar	3.0 bar	5.0 bar
UK	90%	90%	75%
DE	90%	75%	50%
NL	90%	75%	50%

4.3.2 Measurement protocol

The measurement protocol used was identical to that used for LERAP star rating measurements in the UK[1]. Work was carried out to BS ISO 17025:2017 to which SSAU are accredited by UKAS (United Kingdom Accreditation Services). The basic principles of the protocol are outlined below.

The wind tunnel was set up with a single moving nozzle mounted at 0.5 m above the lowest collectors (which were 0.1 m above the floor) on a track sprayer. The layout is shown in Figure 4.1 and a photograph of the tunnel setup prior to the measurements being made is shown in Figure 4.2. The speed of the nozzle was 8 km/h to simulate the constant vehicle speed of a sprayer. The wind speed was set to 2 m/s for all test runs.

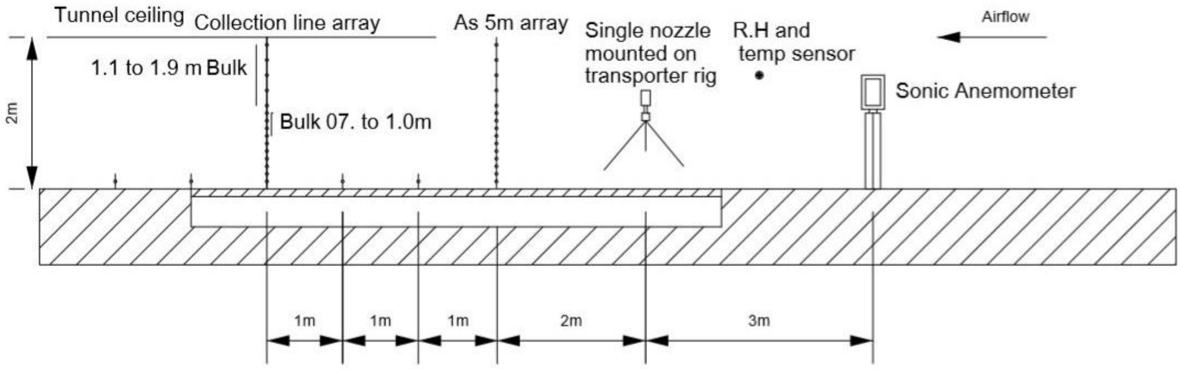

Figure 4.1. Wind tunnel layout.

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[1] UKAS TP1 Appendix, Wind tunnel measurements of measurements of airborne spray profiles

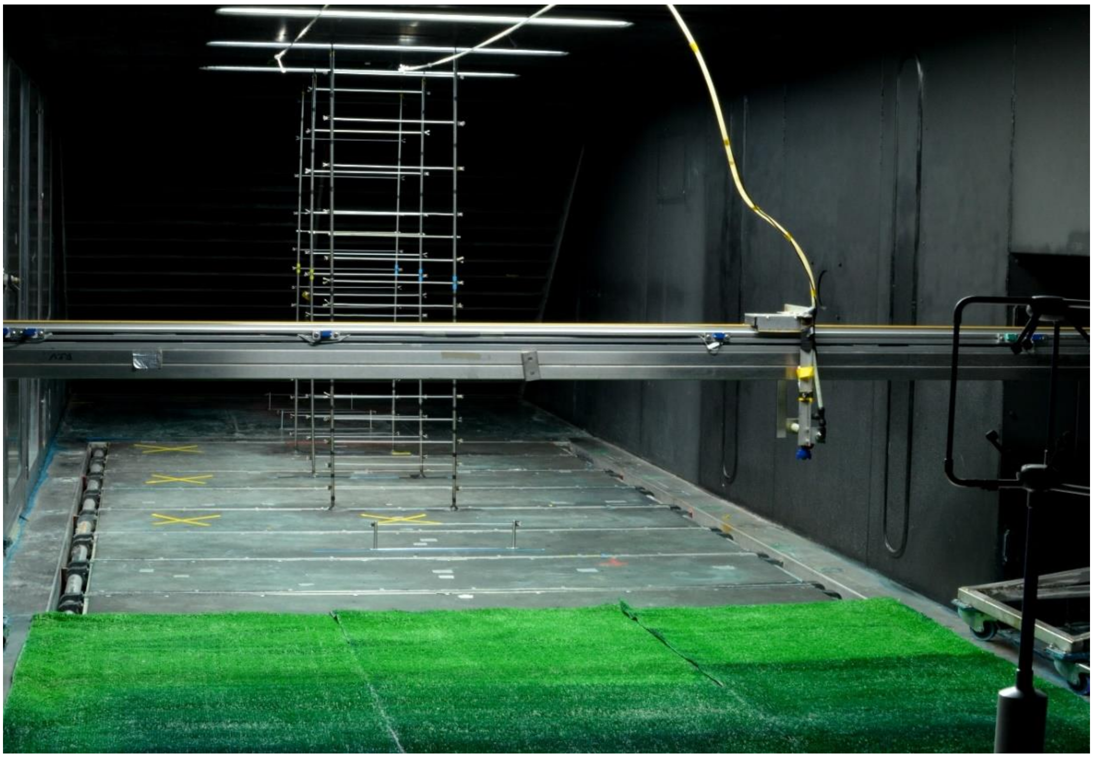

Figure 4.2. Wind tunnel set up with sonic anemometer (foreground, right hand side) upstream of the air flow and collector lines downwind of the nozzle.

The number of passes required to achieve quantifiable drift deposits is dependent upon the level of drift. Hence, 10 passes were used for the reference nozzles and up to 80 passes for the 90 % drift reduction nozzles.

Polythene collector lines (0.5 m long, 0.002 m diameter) were mounted across the tunnel, downwind of the nozzle output to measure both horizontal and vertical profiles:

Horizontal profile:

Collector lines mounted at 0.1 m about ground level, at 2, 3, 4, 5, 6 and 7 m distances from the nozzle.

Vertical profile:

Collector lines mounted at the heights given in Table 4, then combined into three samples. Vertical profiles were obtained at 3 and 5 m downwind distances from the nozzle, as shown in Table 4.3.

- Individual lines 0.1 m to 0.6 m (nozzle height) at 0.1 m spacing
- Combine 0.7 to 1.0 m (0.1 m spacing)
- Combine 1.1 to 1.9 m (0.2 m spacing)

Three replicate tests were made per treatment.

The deposited spray was recovered from each collector by agitation in a known volume of deionised water. Samples were analysed using UV/visible spectrophotometry. Standard curves were prepared from each tank mix at concentrations of 0.5, 1, 5 and 10 µl/ml deionised water. Quantifications were made with a Thermo Fisher Scientific Evolution 201 spectrophotometer (S/N 5A4W018102) set to a

λ_{max} of 634 nm (8/5/2018). System suitability test (SST) samples were used to confirm the instruments performance during setting up with analytical quality control (AQC) samples to check ongoing performance during sample runs. The results were referenced against respective calibrations curves and adjusted to allow for extraction volumes.

Table 4.3. Vertical profile sampling regime

Height above ground, m	Analysis sample number
1.9	8
1.7	8
1.5	8
1.3	8
1.1	8
1.0	7
0.9	7
0.8	7
0.7	7
0.6	6
0.5	5
0.4	4
0.3	3
0.2	2
0.1	1

4.4 Data analysis

The quantity of spray liquid recovered from each of the collecting lines from the six nozzle/pressure combinations tested was analysed in the following way:

The data are normalised for the number of passes and for the nozzle flow rate, relative to that for the reference nozzle under consideration.

The lowest collecting lines (0.1 m above the floor, from 2.0 to 7.0 m downwind) for the UK and NL reference nozzles were used as the baseline for zero drift reduction for the two countries. For the UK, the average of 2 – 7 m downwind was taken, and for NL, the average of 2-3 m downwind.

The 2.0 m vertical profile from the DE reference nozzle (0.1 to 0.6 m above the ground) was used to calculate a 'DIX' value (Herbst and Ganzelmeier, 2000) which was then used as the baseline for zero drift reduction for DE.

The same values were obtained from the three drift-reducing nozzle/pressures, to give an estimate of the actual drift reduction (as opposed to the classification shown in table 4.2) that would be achieved by the different classification schemes. It must be emphasised that these are not identical to the values that were measured by the testing laboratory, which are not in the public domain, but are estimated using principles similar to those used in each of the testing laboratories.

The component of airborne spray relevant to two different measures of bystander exposure were then determined for the six treatments at 2.0 and 5.0 m downwind:

- Dermal exposure (child) - airborne spray up to 1.0 m above the ground
- Dermal exposure (adult) - airborne spray up to 2.0 m above the ground

The differences between adult and child potential exposure will be much lower in the wind tunnel than in the field because of very low dispersion in the vertical direction in the wind tunnel, so that the majority of the spray is collected within 0.5 m of the wind tunnel floor. For the same reason, we have not identified values relevant to inhalation exposure (taken as 0.7 m and 1.4 m above ground for children and adults respectively in BREAM) as, at these heights, spray concentration is much lower than would be achieved in the field.

These averaged airborne spray values were then used to determine a potential dermal exposure reduction compared with each of the reference nozzles.

4.5 Results and discussion

The quantity of spray recovered from each collecting line is given in Appendix 1. These data are then used to determine the quantities outlined in 4.4 above.

Table 4.4 shows the actual drift reduction relative to each reference nozzle, using a calculation method as close as possible to the country's own method.

Table 4.4 Actual drift reduction relative to each reference nozzle, using a calculation method comparable with the country's own method.

	2.0 bar	3.0 bar	5.0 bar
Reference nozzle	90%	75-90%	50-75%
UK	95.40	92.93	91.06
NL	96.25	93.73	89.10
DE	94.40	90.54	87.40

The measured drift reduction is higher than the classification would suggest for the two higher pressure settings. This is likely to be caused by differences in the data produced by the UK wind tunnel, the German wind tunnel and the Dutch model which we cannot quantify in this study. It shows, however, that the other differences, between using vertical and horizontal profiles, and between the reference nozzles, are relatively small. It should be noted that the German and Dutch protocols are based on measured drift closer to the nozzle than the UK protocol (2.0 m, 2 - 3 m and 2 – 7 m respectively) which is probably the reason why the difference in drift reduction between the three nozzle settings are least for the UK.

Tables 4.5 and 4.6 show the reduction in potential bystander exposure, based on airborne spray collected at 2.0 and 5.0 m downwind of the nozzle.

Table 4.5. Potential bystander exposure reduction, based on airborne spray, at 2.0 m downwind in the wind tunnel

	Adult			Child		
	90%	75-90%	50-75%	90%	75-90%	50-75%
UK	95.72	93.04	89.60	95.85	93.27	89.43
NL	96.02	93.54	90.34	96.11	93.69	90.09
DE	95.29	92.35	88.57	95.43	92.58	88.35

Table 4.6. Potential bystander exposure reduction, based on airborne spray, at 5.0 m downwind in the wind tunnel

	Adult			Child		
	90%	75-90%	50-75%	90%	75-90%	50-75%
UK	92.80	94.01	93.96	92.72	94.51	94.18
NL	94.08	95.07	95.03	93.32	94.97	94.66
DE	90.29	91.92	91.85	90.05	92.50	92.05

These data are summarised in Figs 4.3 and 4.4, where the potential exposure reduction is plotted against the actual drift reduction measured according to a standard protocol as close as possible to that used in each of the three countries.

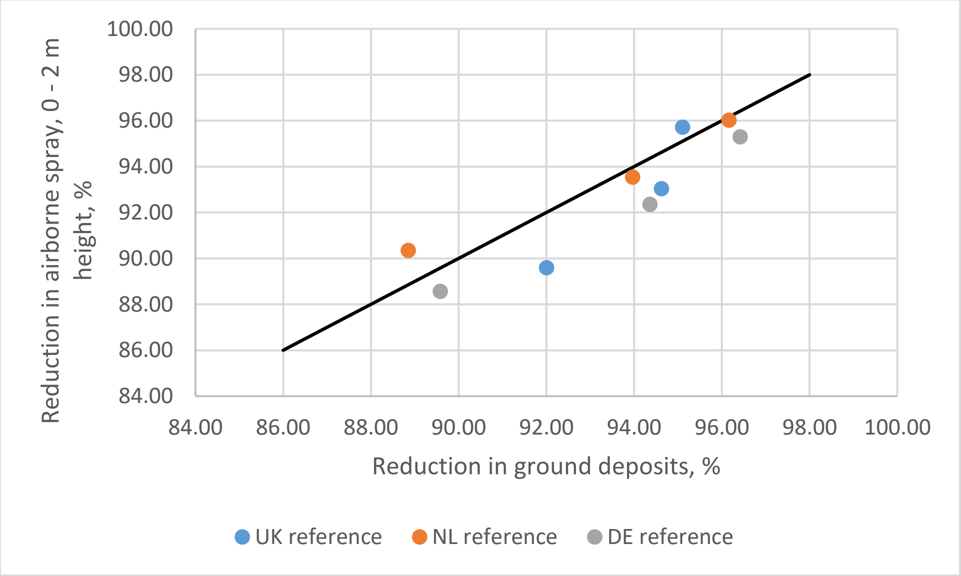

Figure 4.3 Comparison of reduction in total airborne spray with reduction in ground deposits at 2.0 m downwind, for the UK, NL and DE reference nozzles. The black line indicates equivalence.

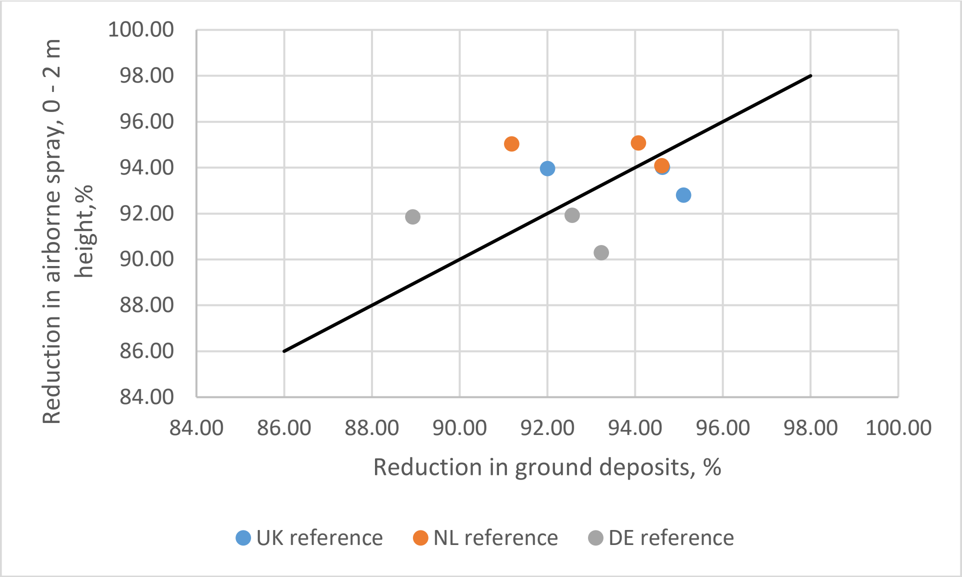

Figure 4.4 Comparison of reduction in total airborne spray with reduction in ground deposits at 5.0 m downwind, for the UK, NL and DE reference nozzles. The black line indicates equivalence.

At 2 m downwind, there is a good correlation between potential exposure reduction and reduction in ground deposits, and differences are all within 2%. At 5 m downwind, there is more scatter in the data, and the correlation is poorer. The 90% DR nozzle gave lower potential exposure reduction than ground deposit reduction, whereas the 50-75% nozzles gave higher reductions in potential exposure. However, all differences are within 5% and the exposure reduction is greater than 90% in all cases. To explore whether there is a decrease in exposure reduction with either distance downwind or with the greatest drift reduction, further data would be needed with a wider range of nozzles.

4.6 Conclusions

In the analysis we have undertaken, we have aimed to identify small, but consistent trends which might suggest that under field conditions, the use of drift reducing nozzles might not give the levels of exposure reduction that their classification might suggest. Such trends were not apparent.

The potential reduction in exposure from the use of drift reducing nozzles is at least as great as the drift-reduction determined from standardised wind tunnel tests.

There is a suggestion that at 5 m downwind and with the highest drift reduction, the potential exposure reduction might be reduced, but there is insufficient data to be conclusive. This wind tunnel data needs to be considered in the context of field data and model simulations.

5. Model Simulations

5.1 Introduction

The Silsoe spray drift model (SiMoD) (Butler Ellis and Miller, 2010) was used to explore further some of the issues we have been unable to address with existing data or wind tunnel tests. In particular, the wind tunnel studies are conducted under plug flow conditions with low turbulence, whereas atmospheric flows have a logarithmic wind speed profile with much higher turbulence which leads to greater dispersion of airborne spray. While the model is less able to simulate the complexity of the nozzle and airflows around it than the wind tunnel, it does include a more realistic description of an atmospheric flow. Thus model data are complementary to wind tunnel data, with the additional advantage of being able to simulate greater distances downwind.

Another advantage of the model is that we can investigate the effect of different crops on drift reduction. Some additional model simulations were made to identify whether the effect of the presence of a crop on reducing potential bystander exposure is similar to that identified from the OBO data shown in Figure 3.2.

5.2 Simulations

Model input data was obtained using a droplet imaging technique (Murphy *et a*l, 2001) to determine the droplet size and velocity distribution of droplets produced by each of the six nozzle/pressure combination used in the wind tunnel study in section 4. A simulation for each nozzle was undertaken, using a wind speed of 2.7 m/s at 2.0 m height, a boom height of 0.5 m, a forward speed of 12 m/s and a single pass of a 24 m boom width. The choice of these parameters is largely arbitrary, and we would expect measures of drift reduction to be relatively insensitive to them. However, we have aimed to be consistent either with the experimental data in the OBO trials or wind tunnel experiments, or defined by the BREAM defaults (EFSA, 2014)

The model produces a matrix of data relating to ground deposits and airborne spray concentrations at a range of distances downwind and heights above the ground. Potential child and adult dermal exposure are based on total airborne spray between 0 and 1.0 m and 0 and 2.0 m above the ground respectively, and potential child and adult inhalation exposure are based on airborne spray concentration at 0.7 m and 1.4 m above ground respectively.

Simulations were undertaken for bare ground and two different crops of height 0.5 m. One represented a low density drop with a very low droplet capture efficiency, which might best represent an onion crop such as the one used in the OBO trials, and the other with a higher droplet capture efficiency that might be representative of a denser crop such as cereals.

5.3 Model outputs

Figure 5.1 shows examples of the relationship between the estimates of reduction in exposure based on vertical profile, and the reduction in drift based on a horizontal profile at four distances downwind. These data are for a child bystander (i.e. dermal exposure is from 0 – 1 m height, and inhalation at 0.7 m height). Similar relationships are found for the adult exposure estimates.

It can be seen that in all cases that the reduction in exposure is at least as great as the reduction in ground deposit.

The simulations with a crop present show the same behaviour whether the crop is high or low density. This is shown in Figure 5.2 for the low-density crop.

The simulated data for just the 90% DR nozzle, compared with the NL reference, for potential dermal exposure for adult and child is plotted in Figure 5.3. This is the predicted version of Figures 3.1 and 3.2, and is not consistent with the field data from the OBO project, which suggested that exposure reduction when spraying over a crop is less than that determined from ground deposits.

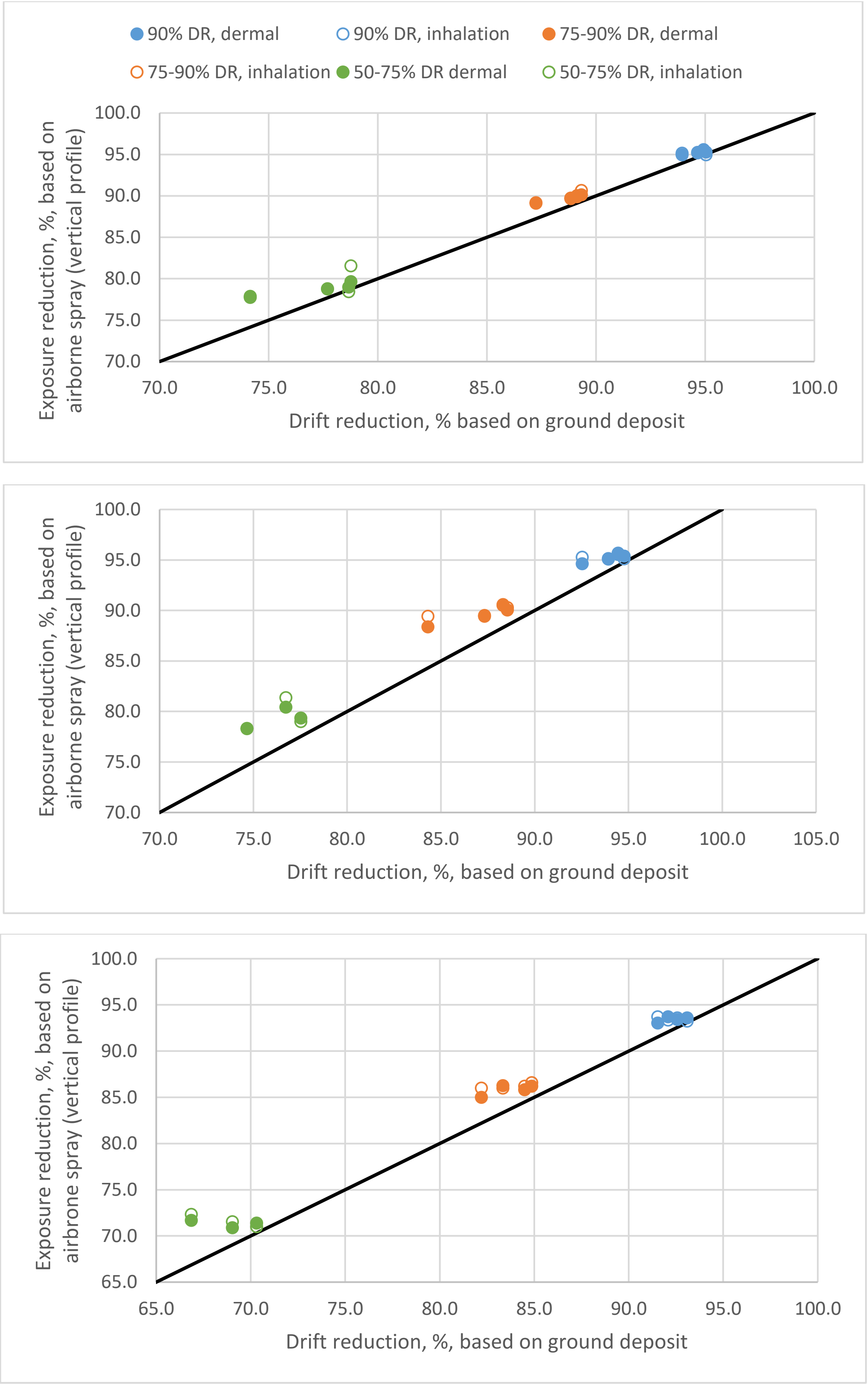

Figure 5.1 Relationship between estimates of reduction in exposure and the reduction in drift based on a horizontal profile at four distances downwind for a child bystander (i.e. dermal exposure is from 0 – 1 m height, and inhalation at 0.7 m height) when spraying over a short crop or bare soil. Top – UK reference; middle – DE reference; bottom – NL reference.

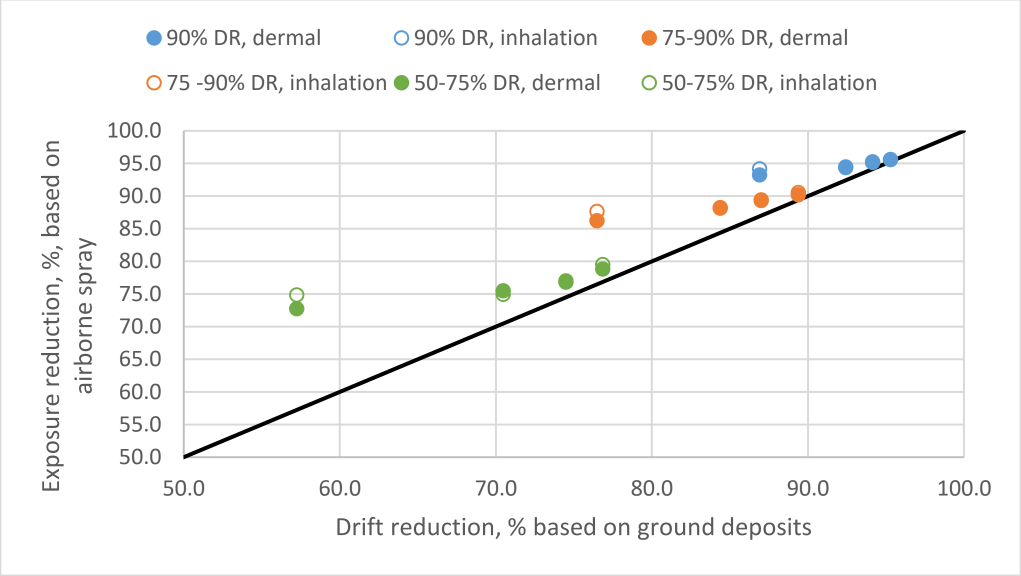

Figure 5.2 Relationship between estimates of reduction in exposure and the reduction in drift based on a horizontal profile at four distances downwind for a child bystander (i.e. dermal exposure is from 0 – 1 m height, and inhalation at 0.7 m height) when spraying over a low density crop of 0.5 m height. Drift reduction based on UK reference nozzle.

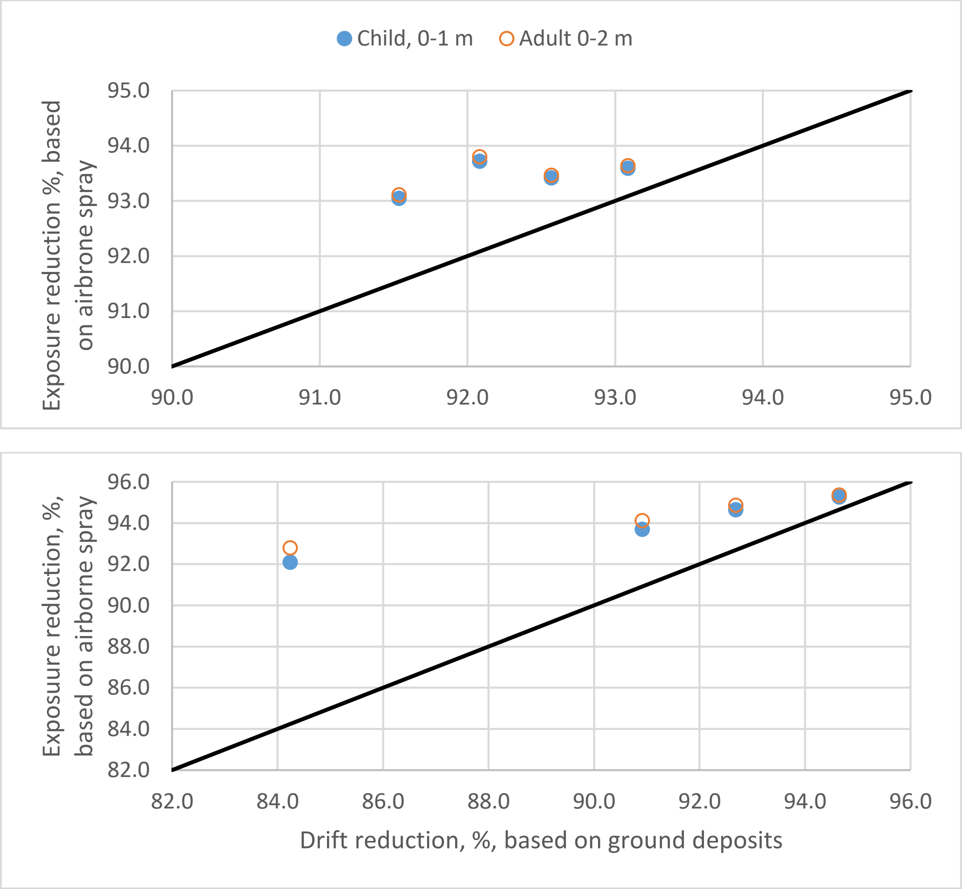

Figure 5.3 Drift reduction based on model simulations based on the 90% DR nozzle compared with the Dutch reference nozzle for bare ground (top) and a low density 0.5 m tall crop (bottom)

6. Implications for regulatory exposure assessment

When selecting drift-reducing equipment for application of plant protection products, users do not know the exact levels of drift reduction, but only which class the equipment falls. Classes vary between different European countries, but the differences between the UK, German and Dutch systems are small. The width of the 50% and 75% drift-reducing classes is such that unless the test system is very close to a boundary, it is likely to give the same classification for all three countries.

The drift-reduction class is defined by field measurements of ground deposits, wind tunnel measurements of horizontal or vertical profiles, or use of a model to predict ground deposits, none of which directly relate to airborne spray in the field, which is the component of spray drift which is relevant to dermal and inhalation exposure.

Questions therefore arise as to whether this drift reduction classification can be applied to potential bystander dermal and inhalation exposure under some or all application scenarios. The variables we have aimed to investigate in this study are

- Distance downwind
- Level of drift reduction
- Reference nozzles and drift reduction classification method
- Presence of a crop
- Use of formulated products

and combinations of the above.

Because of a shortage of relevant data relating to measurements of bystander exposure, we use data for airborne spray where necessary as a surrogate for potential exposure.

The OBO data includes distances downwind between 5 and 20 m and presence/absence of a crop for airborne spray. Glass *et al* data includes a lower level of drift reduction than OBO, and actual potential bystander dermal exposure.

The data obtained in the SSAU wind tunnel for Syngenta includes a range of drift reductions and commercial products.

New wind tunnel data explored how the different reference nozzles and classification schemes might affect the outcomes

Model simulations considered all the variables apart from the use of formulated products.

The majority of the data show that the reduction in potential exposure of bystanders by using drift reducing nozzles is at least as great as the reduction in ground deposits at the same location downwind. Further analysis suggests that the potential exposure reduction is also greater than the reduction in drift as measured with the either the UK, DE or NL protocols.

Because the DR classes are wide, most nozzles give greater drift reduction than the class they are in, unless they are close to the boundary. Clearly, where drift reduction is greatest (90% drift reduction) more nozzles will be close to the boundary and a nozzle given a 90% drift reduction rating based on one protocol might not always deliver a 90% reduction in airborne spray or potential bystander exposure. However, in terms of practically defining levels of exposure for regulatory purposes, we believe that the real exposure reduction would not be statistically significant from the 90% value.

Thus we can conclude that the drift reduction class for a given nozzle, provided that nozzle is used with the appropriate spraying conditions which include pressure and boom height, can be used to reduce the predicted exposure of residents and bystanders. This would apply to nozzles that have been classified according to the UK, NL or German protocols.

In considering whether we could also include nozzles classified under the French scheme, we need to establish the difference between the reference conditions. Stallinga et al (2018) showed that the NL/UK reference condition would give ground deposit drift levels which give approximately 75% drift reduction compared with the French reference. The French scheme has only one drift-reducing class, of 66%, and therefore the UK, NL and German reference nozzles themselves achieve drift reduction status under the French protocol. Thus we cannot draw any conclusions about the actual levels of drift reduction achieved by the French classification scheme, and nozzles that have only the French classification cannot be included.

7. Recommendations

The current model of bystander exposure allows a reduction in exposure of 50% when drift-reducing techniques are employed. The data available strongly suggest that greater reductions in exposure can be supported for higher levels of drift reduction:

- A 75% drift-reducing nozzle will deliver 75% reduction in dermal and inhalation exposures, and in exposures from contact with ground deposits.
- A 90% drift-reducing nozzle will deliver 90% reduction in dermal and inhalation exposures, and in exposures from contact with ground deposits.

This applies to equipment classified under the UK, NL or German schemes providing all the conditions associated with the classification (such as pressure and boom height) are also followed.

Moreover, these levels of airborne spray reduction should apply at any location between 2 and 20 m downwind of the sprayed area so that it would be possible to combine drift reduction with a no spray zone to achieve a high level of mitigation.

The BREAM2 model does not currently include a crop, because of historical difficulties with predicting drift with the emulators which are used. An area of future development of the model would be to use the latest version of SiMoD to build new emulators, following on from developments undertaken in the BROWSE project. More data relating to exposures or airborne spray in the field over a range of crops, and data to provide an estimate of the confidence intervals relating to the measured exposures, would both be valuable.

The most cost-effective approach to implementing the findings of this study into the BREAM2 model would be to leave the model unchanged but allow a reduction in predicted exposures to be calculated manually. Clearly, a more sophisticated approach is possible by including a built-in calculation that includes drift reduction. There is, however, no need to change the basis of the model, or the drift emulators, to include drift reduction, so this would be a relatively modest change to the software.

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8. <u>Appendix 1 Certificate of analysis from wind tunnel experiment.</u>

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SILSOE SPRAY APPLICATIONS UNIT LTD

CERTIFICATE OF ANALYSIS

Report ID: S0252

Title: Study to support the introduction of mitigation from spray drift reduction into the BREAM2 model.

Date of Issue: 20/12/2019

Customer: European Crop Protection Agency

Customer Contact: Christian Kuster, Stéphanie Nadzialek

Method ID: Quantification of Green S by UV/visible spectrophotometry TP2 Appendix 2 Issue 9

Limit of Detection: 0.002 µl/ml

Deviations from method: NONE

Date Sampled: 11th to 12th November 2019
Date received: 12th to 13th November 2019
Date analysed: 12th to 13th November 2019

Location: Wind tunnel at Silsoe Spray Applications Unit

Sampling plan: Protocol for Airborne drift in the wind tunnel to inform bystander exposure S0252 V3 (11/11/2019)

Sample description: Samples generated during on-site testing were provided as extracted solutions for analysis of Green S tracer.

Wind tunnel collectors	Dimension
Horizontal lines	0.5m x 1.98mm

Results are expressed in terms of µls of the spray tank liquid on each set of collectors.
Sample code is run number (1 – 18), distance downwind (1, 2, 3, 4, 5, 6 m), height above the ground as detailed in table 1. Three replicate runs for each of 3 nozzle types tested.

- Spray liquid: 0.1% (w/v) Green S with 0.1% (w/v) Tween 20.
- Solvent used for extraction of analyte: Deionised water

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Table 1. Labelling system	Sampled	Height(s), m
For distances 3, 4, 6, and 7 m	Single line	0.1
For distances 2 and 5 m	Individual line	0.1
	Individual line	0.2
	Individual line	0.3
	Individual line	0.4
	Individual line	0.5
	Individual line	0.6
	Bulked 4 lines (0.1 m spacing)	0.7 to 1.0
	Bulked 5 lines (0.2 m spacing)	1.1 to 1.9

Results Summary

Sample	Recovered tank (µl)	Bulked lines	Sample	Recovered tank (µl)	Bulked lines
1-2.1	30.46	1	10-2.1	6.7	1
1-2.2	20.26	1	10-2.2	4.31	1
1-2.3	4.38	1	10-2.3	2.09	1
1-2.4	0.84	1	10-2.4	0.92	1
1-2.5	0.36	1	10-2.5	0.37	1
1-2.6	0.30	1	10-2.6	0.26	1
1-2.7	0.32	4	10-2.7	0.67	4
1-2.8	0.83	5	10-2.8	0.79	5
1-3.1	13.66	1	10-3.1	2.82	1
1-4.1	6.47	1	10-4.1	1.81	1
1-5.1	4.01	1	10-5.1	1.17	1
1-5.2	2.69	1	10-5.2	0.83	1
1-5.3	1.77	1	10-5.3	0.61	1
1-5.4	0.79	1	10-5.4	0.42	1
1-5.5	0.71	1	10-5.5	0.4	1
1-5.6	0.44	1	10-5.6	0.5	1
1-5.7	1.33	4	10-5.7	0.55	4
1-5.8	1.25	5	10-5.8	0.57	5
1-6.1	2.50	1	10-6.1	0.96	1
1-7.1	1.66	1	10-7.1	0.63	1
2-2.1	34	1	11-2.1	11.47	1
2-2.2	27.41	1	11-2.2	7.55	1
2-2.3	7.35	1	11-2.3	3.07	1
2-2.4	2.14	1	11-2.4	0.41	1
2-2.5	0.31	1	11-2.5	0	1
2-2.6	1.17	1	11-2.6	0	1
2-2.7	2.9	4	11-2.7	0	4
2-2.8	1.22	5	11-2.8	0.13	5
2-3.1	15.17	1	11-3.1	4.43	1
2-4.1	7.13	1	11-4.1	2.24	1
2-5.1	4.4	1	11-5.1	1.33	1
2-5.2	3.83	1	11-5.2	0.76	1
2-5.3	2.31	1	11-5.3	0.22	1
2-5.4	1.41	1	11-5.4	0	1

Sample	Recovered tank (µl)	Bulked lines	Sample	Recovered tank (µl)	Bulked lines
2-5.5	1.38	1	11-5.5	0	1
2-5.6	1.08	1	11-5.6	0	1
2-5.7	2.28	4	11-5.7	0.08	4
2-5.8	1.51	5	11-5.8	0.22	5
2-6.1	3.05	1	11-6.1	0.67	1
2-7.1	2.53	1	11-7.1	0.44	1
3-2.1	27.86	1	12-2.1	30.77	1
3-2.2	15.84	1	12-2.2	20.63	1
3-2.3	1.76	1	12-2.3	6.44	1
3-2.4	0.71	1	12-2.4	0.69	1
3-2.5	0.83	1	12-2.5	0.2	1
3-2.6	0.76	1	12-2.6	0	1
3-2.7	1.83	4	12-2.7	0.63	4
3-2.8	1.66	5	12-2.8	1.05	5
3-3.1	9.37	1	12-3.1	12.82	1
3-4.1	4.55	1	12-4.1	5.81	1
3-5.1	3.22	1	12-5.1	3.33	1
3-5.2	2.75	1	12-5.2	1.89	1
3-5.3	1.58	1	12-5.3	0.78	1
3-5.4	1.06	1	12-5.4	0.2	1
3-5.5	0.83	1	12-5.5	0	1
3-5.6	0.37	1	12-5.6	0	1
3-5.7	1.47	4	12-5.7	0.7	4
3-5.8	0.62	5	12-5.8	1.25	5
3-6.1	2.3	1	12-6.1	2.03	1
3-7.1	1.68	1	12-7.1	1.09	1
4-2.1	5.83	1	13-2.1	21.2	1
4-2.2	3.99	1	13-2.2	15.61	1
4-2.3	1.85	1	13-2.3	3.8	1
4-2.4	0.77	1	13-2.4	0.07	1
4-2.5	0.38	1	13-2.5	0	1
4-2.6	0.32	1	13-2.6	0.09	1
4-2.7	0.51	4	13-2.7	0.35	4
4-2.8	0.52	5	13-2.8	0.59	5
4-3.1	2.67	1	13-3.1	11.1	1
4-4.1	1.78	1	13-4.1	5.69	1
4-5.1	1.14	1	13-5.1	4.19	1
4-5.2	0.94	1	13-5.2	2.97	1
4-5.3	0.71	1	13-5.3	1.93	1
4-5.4	0.61	1	13-5.4	1.56	1
4-5.5	0.65	1	13-5.5	1.63	1
4-5.6	0.36	1	13-5.6	1.65	1
4-5.7	0.53	4	13-5.7	0.61	4
4-5.8	0.5	5	13-5.8	0.83	5
4-6.1	0.88	1	13-6.1	1.91	1
4-7.1	0.8	1	13-7.1	1.19	1
5-2.1	12.41	1	14-2.1	30.68	1

Sample	Recovered tank (µl)	Bulked lines	Sample	Recovered tank (µl)	Bulked lines
5-2.2	8.32	1	14-2.2	22.36	1
5-2.3	4.56	1	14-2.3	5.45	1
5-2.4	2.15	1	14-2.4	2.09	1
5-2.5	1.83	1	14-2.5	0.94	1
5-2.6	1.72	1	14-2.6	0.42	1
5-2.7	2.27	4	14-2.7	2.45	4
5-2.8	1.9	5	14-2.8	1.75	5
5-3.1	6.98	1	14-3.1	11.86	1
5-4.1	2.83	1	14-4.1	5.8	1
5-5.1	1.9	1	14-5.1	4.14	1
5-5.2	1.66	1	14-5.2	3.17	1
5-5.3	1.41	1	14-5.3	2.13	1
5-5.4	1.11	1	14-5.4	1.35	1
5-5.5	1.36	1	14-5.5	1.58	1
5-5.6	1.5	1	14-5.6	1.31	1
5-5.7	1.55	4	14-5.7	3.39	4
5-5.8	1.65	5	14-5.8	3.37	5
5-6.1	2.84	1	14-6.1	3.91	1
5-7.1	2.55	1	14-7.1	2.95	1
6-2.1	26.2	1	15-2.1	24.61	1
6-2.2	18.21	1	15-2.2	14.8	1
6-2.3	6.02	1	15-2.3	2.22	1
6-2.4	0.91	1	15-2.4	0.12	1
6-2.5	0.31	1	15-2.5	0.06	1
6-2.6	0.3	1	15-2.6	0	1
6-2.7	0.44	4	15-2.7	0.92	4
6-2.8	0.57	5	15-2.8	0.48	5
6-3.1	11.52	1	15-3.1	9	1
6-4.1	5.48	1	15-4.1	3.74	1
6-5.1	3.34	1	15-5.1	2.4	1
6-5.2	2.28	1	15-5.2	1.37	1
6-5.3	1	1	15-5.3	0.61	1
6-5.4	0.51	1	15-5.4	0.3	1
6-5.5	0.38	1	15-5.5	0	1
6-5.6	0.77	1	15-5.6	0.09	1
6-5.7	0.79	4	15-5.7	1.25	4
6-5.8	0.73	5	15-5.8	1.09	5
6-6.1	2.36	1	15-6.1	1.35	1
6-7.1	1.52	1	15-7.1	0.88	1
7-2.1	20.52	1	16-2.1	5.93	1
7-2.2	13.55	1	16-2.2	3.7	1
7-2.3	3.69	1	16-2.3	1.64	1
7-2.4	0.84	1	16-2.4	0.48	1
7-2.5	0.71	1	16-2.5	0.06	1
7-2.6	0.63	1	16-2.6	0	1
7-2.7	1.11	4	16-2.7	0.2	4
7-2.8	1.31	5	16-2.8	0.22	5
7-3.1	9.41	1	16-3.1	2.46	1

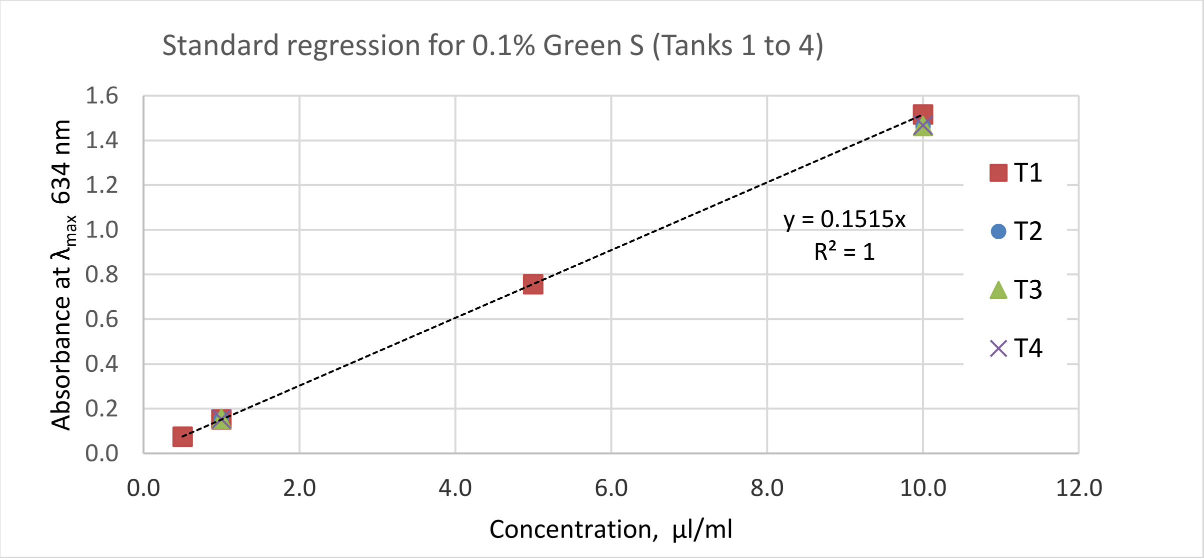
Sample	Recovered tank (µl)	Bulked lines	Sample	Recovered tank (µl)	Bulked lines
7-4.1	4.9	1	16-4.1	1.64	1
7-5.1	2.75	1	16-5.1	1.46	1
7-5.2	1.88	1	16-5.2	1.14	1
7-5.3	1.08	1	16-5.3	1.2	1
7-5.4	0.67	1	16-5.4	1.43	1
7-5.5	0.53	1	16-5.5	1.67	1
7-5.6	0.37	1	16-5.6	1.06	1
7-5.7	0.96	4	16-5.7	0.24	4
7-5.8	1.03	5	16-5.8	0.43	5
7-6.1	1.97	1	16-6.1	0.5	1
7-7.1	1.37	1	16-7.1	0.47	1
8-2.1	31.19	1	17-2.1	11.52	1
8-2.2	25.52	1	17-2.2	7.37	1
8-2.3	7.33	1	17-2.3	3.44	1
8-2.4	1.72	1	17-2.4	1.09	1
8-2.5	1.15	1	17-2.5	0.73	1
8-2.6	0.58	1	17-2.6	0.43	1
8-2.7	2.84	4	17-2.7	0.79	4
8-2.8	2.4	5	17-2.8	1.05	5
8-3.1	16.16	1	17-3.1	5.76	1
8-4.1	8.61	1	17-4.1	3.78	1
8-5.1	5.39	1	17-5.1	1.82	1
8-5.2	3.64	1	17-5.2	0.65	1
8-5.3	2.66	1	17-5.3	0.25	1
8-5.4	1.47	1	17-5.4	0.03	1
8-5.5	1.31	1	17-5.5	0	1
8-5.6	1.18	1	17-5.6	0.04	1
8-5.7	3.19	4	17-5.7	0.53	4
8-5.8	3.54	5	17-5.8	0.5	5
8-6.1	3.24	1	17-6.1	1.71	1
8-7.1	2.86	1	17-7.1	0.74	1
9-2.1	27.06	1	18-2.1	26.62	1
9-2.2	14.7	1	18-2.2	17.9	1
9-2.3	1.63	1	18-2.3	5.4	1
9-2.4	0.51	1	18-2.4	0.58	1
9-2.5	0.68	1	18-2.5	0.17	1
9-2.6	0.56	1	18-2.6	0	1
9-2.7	1.08	4	18-2.7	0.34	4
9-2.8	0.88	5	18-2.8	0.36	5
9-3.1	8.82	1	18-3.1	11.64	1
9-4.1	4.34	1	18-4.1	5.47	1
9-5.1	2.98	1	18-5.1	2.93	1
9-5.2	2.28	1	18-5.2	1.76	1
9-5.3	1.35	1	18-5.3	0.52	1
9-5.4	1.17	1	18-5.4	0.18	1
9-5.5	0.91	1	18-5.5	0	1
9-5.6	0.44	1	18-5.6	0.04	1
9-5.7	0.93	4	18-5.7	0.55	4

Sample	Recovered tank (µl)	Bulked lines	Sample	Recovered tank (µl)	Bulked lines
9-5.8	1.02	5	18-5.8	0.53	5
9-6.1	2.08	1	18-6.1	1.76	1
9-7.1	1.47	1	18-7.1	1.17	1

Standard Tank reference results

	Absorbance at 634 nm			
Concentration, µl tank ref/ ml	0.5	1	5	10
T1	0.074	0.151	0.756	1.516
T2		0.153		1.462
T3		0.154		1.464
T4		0.153		1.467

Standard regression



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