Field Measurements of Spray Drift Potential in Strawberry

N. Bjugstad and P. Hermansen

Department of Mathematical Sciencies and Technology, Norwegian University of Life Sciencies, Postbox 5003, N-1432 Ås, Norway.
nils.bjugstad@umb.no, petter.hermansen@umb.no

ABSTRACT

Passive drift samplers were mounted on a frame, attached to the sprayer, 2 m behind the nozzles of different strawberry spraying systems. The spraying systems were operated at a common tractor speed of 7.2 km/h. At calm wind conditions this forward speed corresponded to a wind speed of approximately 2 m/s causing potential drift from the nozzles. Drift samplers, made of cotton and acryl thread of 2 mm diameter and 3 m long, were mounted horizontally on a frame at different heights up to 2.0 m above the ground. Measurements compared at different growth stages in May (1) and August (2) demonstrated that drift was reduced by 75% due to the increased filter effect of the leaf density in August. The drift from a tunnel sprayer was 10 and 13% of a reference sprayer when using an end-curtain and 55% and 37% without any end-curtain at growth stages 1 and 2, respectively. At growth stage 1, using 80 015 nozzles at 200 mm from the plants gave a significant increase in drift compared with the similar nozzles at 100 mm from the plants. At growth stage 2 the reference sprayer at 1.0 MPa gave a significantly higher drift than at 0.5 MPa. Using air injection nozzles (ID nozzles) reduced the drift significantly.

Keywords: wind speed, sampling method, nozzle type, nozzle distance, nozzle pressure, growth stage, air induction nozzle, field measurement

1. INTRODUCTION

This paper reports the results of a project aimed at improving spraying equipment in strawberry production in Norway. It was a collaborative project between the Norwegian Crop Research Institute and the Department of Mathematical Sciences and Technology at the University of Life Sciences during the period 2002-2006. Results from deposit measurements are presented (Bjugstad and Sønsteby, 2004). This paper focuses on the drift measurements from strawberries because the risk of drift is estimated to be high due to; a fixed driving direction, frequent applications and the fact that strawberry plants are difficult to spray properly. Several studies are carried out regarding drift measurements (i.e. Arvidsson, 1997; Nuyttens, 2007; Zande *et al*, 2002), but only a few measurements are earlier reported considering drift measurements in strawberry fields. In Denmark, drift measurements for strawberry application were made by comparing different sprayers in alfalfa field established in 50 cm rows to simulate a strawberry crop (Jensen and Spliid, 2005). In the U.S., long distance measurements of methyl bromide drift by air samplers were reported (Kegley *et al*, 2001). The spraying equipment and particularly the nozzle characteristics are important factors to reduce the drift hazard (Miller, 1999; Nuyttens, 2007). Drift modelling has been carried out for a lot of different spraying applications (Lund, 2008; Nuyttens *et al*, 2006).

However, this is not done for strawberry sprayers, probably due to too many temporally and spatially changing parameters influencing the drift potential.

This is why there is a high need for drift potential measurements when spraying in strawberries. In Norway the use of small and hilly fields for strawberry production and the large variations in wind speed and direction make it difficult to adapt the ISO standards for drift measurements. Thus, a special design of spraying equipment and drift samplers were made to enable a quick risk assessment of the potential drift. The position and size of the samplers were harmonised due to the existing standards for drift studies (ISO 22369-1, ISO/DIS 22369-2 and ISO 22866).

2. OBJECTIVES

The main objectives for this study were to;

- Find simple methods to measure the drift in order to cover several types of equipment and adjustments without major influencing and disturbing metrological factors like changing in wind speed, wind direction, temperature and humidity. By measuring the potential drift, this could be obtained properly.
- Measure the drift potential from a common front mounted sprayer (reference sprayer), a tunnel sprayer with and without curtain and a sprayer earlier developed in the project.

The intention of measuring the potential drift (phase 1 drift) is because this drift is quicker to measure, more exact and less time consuming than the drift measurement described in the ISO standard for field measurements. This standard measures the phase 2 drift, which is excellent for the study of the environmental impact (Fig. 1). However, these values are a result of several influencing factors in addition to the equipment and adjustment itself. Thus, this method will not be able to distinguish exactly between different application techniques and adjustments in the similar manner as the method described for phase 1 drift measurements. The potential drift (phase 1) is characterised by the release of small droplets from the spray fan by the travel wind mainly influenced by technical parameters (Herbst & Ganzelmeier, 2000).

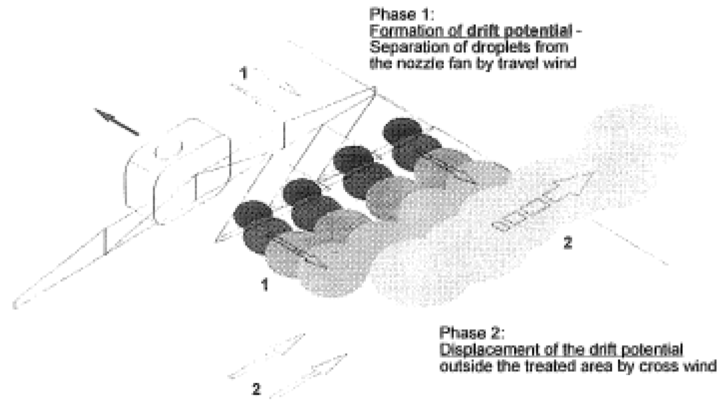
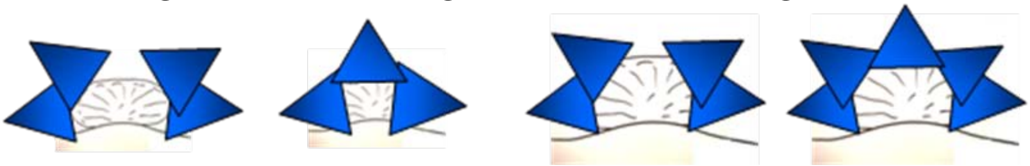


Figure 1: The potential drift (phase 1) is mainly caused by technical parameters. The drift outside treated area (phase 2) is caused by phase 1 and several meteorological parameters, i.e. wind speed, temperature and air humidity (Herbst & Ganzelmeier, 2000).

3. MATERIALS AND METHODS

3.1 Spraying Equipment

All the spraying equipment used in this study was designed for front mounting on a tractor. The trials were sprayed by an experimental prototype, except when using a tunnel sprayer (Klip Klap, DK) and the most commonly used equipment in Norway (LTI – boom, N). The spraying equipment, nozzles, pressure and flow rates are shown in Table 1. The tunnel sprayer was used with and without an end curtain behind the tunnel shield. The sprayer nozzle arrangement is shown in Figure 2 and the tunnel in Figure 3.



a) Stage 1 b) Stage 1 c) Stage 2 d) Stage 2

Figure 2: Nozzle arrangement (position and number) for sprayers at the two growth stages.

a) and c); the reference sprayer, LTI-boom, 1.0 MPa
b) and d); the prototype with three nozzles per row (small plants) and five nozzles per row (large plants).

a) b)

Figure 3: a) Klip Klap tunnel sprayer without and b) with end curtain to reduce drift. Notice the plant canopy opener (smooth spring rod covered with soft material) inside the tunnel.

3.2 Samplers and Position of Samplers

The drift samplers were positioned in order to collect all the potential drift. To avoid saturation and runoff losses from the samplers, they were located at a minimum distance of 2.0 m from the nozzles. Droplets, that sediment between the nozzle outlet and drift collector were assumed to deposit onto the target crop.

The experiments were carried out during very calm wind conditions which mean that the relative velocity of the air surrounding the spray nozzle approximates to be the forward speed of the sprayer (7.2 km/h = 2.0 m/s). The holders of the passive drift samplers were fixed in an approx. 2.5 m height and 3.0 m wide iron frame positioned 2.0 m behind the spraying equipment, perpendicular to the row direction (Fig. 3 and 4). The samplers consisted of 14 horizontal lines of 3 m long and approx. 2 mm diameter white thread *(`Mandarin Fiesta`, Sandnes Garn, 55% cotton, 45% acryl).* The lines were positioned at every 0.10 m in the range of 0.10 to 1.00 m height and then every 0.20 m up to 2.00 m height. The two lowest samplers were eliminated when spraying large plants due to the risk of contamination. Sampler lines made of PVC are used in wind tunnel studies at similar positions and size (Walklate, 1992; Murphy et al., 2000; Saunders, 2002; Gil *et al*, 2005; Nuyttens *et al*, 2009). Cotton ribbons as passive sampling media have been used by others for measuring spray drift (Salyani and Farooq, 2005). Due to the size of the sampling structure and its close distance from the nozzles, the threads were able to sample the full driftable cloud in spite of minor changes in climate conditions. This was controlled by positioning one vertical line at each outer side of the frame for every experiment in order to document that all the droplets were inside the frame. The same row of crop was sprayed for all trials for a length of 40 m within a time of 20 s only corresponding to the forward speed of 7.2 km/h.

The thread lines were fixed to the frame in one piece. By putting a clean transparent plastic bag around a hand, the thread of each level was easily wrapped around the bag. Then the threads were cut off at the end and the plastic bag was turned inside out to enclose the thread. The samples were stored in a chilly and dark place for the later analysis. One replicate, including setting out all the samplers, running the experiments for 20 s and collecting the samplers, took approximately 15 min.

3.3 Methods of Analysis

The spray fluid consisted of water, a fluorescent tracer (0.01 % Fluorescein LT), and a surfactant (0.1% DP). Tank concentration samples were taken before and during the experiment. In totally, 10 techniques were tested at both growth stages (Table 1). Each technique was tested three times which resulted in a total number of 60 experiments. The experiments took approx. 8 hours for each growth stage. The experiments were made in May at an early stage (small plants) and in August 2005 at a late stage (large plants). The average plant size was measured by plant width, plant height and also LAI for five randomly selected plants.

The wind speed close to the treated row was continuously measured 0.2 to 2 metres above the ground by the use of a hot anemometer, as well as the RH (relative humidity) and the temperature. Due to the short time of exposure, the application could be carried out at calm wind conditions. Light and smooth paper strips were positioned along the row and in the surroundings to indicate if any wind disturbances occurred in order to ensure low wind speeds during the short time lasting experiments.

The following day, plastic bags containing the threads were flushed by 100 ml distilled water, and the ppb concentration was measured by a fluorometer (10-AU-005-CE Turner, measuring range 0.001 – 100 ppb).

Figure 4. Frame overview. The equipment mounted is the prototype with nozzle set up. Later a user-friendly 0-serie was built and tested out. Due to practical reasons the nozzle arrangement is closer to the tractor. Thus, the experiments were carried out at zero wind or at weak wind perpendicular away from the tractor to ensure that all the drift was passing the grid in the frame.

Figure 5. Position of threads; 10 cm intervals in range 10 to 100 cm, then every 20 cm up 2 m. Note the vertical line to the right controlling no drift outside the frame. Driving speed 7.2 km/h = 2 m/s. Reference sprayer in action.

According to Table 1 the different nozzles and adjustments gave different flow rates. Thus, the measured data was corrected to the same relative value as for the reference equipment; the

LTI boom at 1.0 MPa, in order to be evaluated correctly. Experimental data were subjected to analysis of variance (ANOVA) by standard procedures using a Minitab version 14-programme package.

3.4 Field and Plant Canopy

The plants were the *Korona* type with an approx. average width of 0.34 m, height of 0.27 m, leaf surface area of 1911 cm^2 and had an average number of 42 leaves/plant at growth stage 1 (small plants) and a width of 0.52 m, height of 0.40 m, leaf surface area of 5286 cm^2 and a number of 76 leaves/plant at growth stage 2 (large plants). One specific single row was treated all the time in order to ensure as good as possible similar biological and climatic conditions.

3.5 Meteorological Data

When spraying at growth stage 1, the natural wind speed varied from 0.3 to 1.8 m/s and the direction from 70 to 90º backwards to driving direction at a height of 0.5 m above the crop. The RH varied from 34 to 70 % and temperature from 12 to 20 ºC measured in the inter row close to the ground (high RH and low temperature in the morning). At the time using the tunnel sprayer, the natural wind dropped down to 0.3 to 0.6 m/s. By the use of paper strips wind indicators and only 20 s of exposure time, the experiments could be carried out at approximately calm and equal conditions as earlier explained.

Table 1. Overview of spraying equipment, nozzles and adjustment according to plant size

Plant Size	No. Nozzles, Nozzle Size and Nozzle Type	Nozzle Distance mm	Nozzle Pressure MPa	Flow Rate L/min nozzle	L/min row
Small	3 x ISO XR80 015*	100	0.5	0.76	2.28
Small	3 x ISO XR80 015*	200	0.5	0.76	2.28
Small	3 x 65 02*	200	0.5	1.01	3.03
Small	3 x 65 02*	100	0.5	1.01	3.03
Small	1 x ISO ID90 02** + 2xISO XR80 03*	100	0.5	1.35	4.05
Small	3 x ISO ID90 02**	100	1.0	1.01	3.03
Small	4 x ISO 80 02*** Tunnel spr.+ curtain	100	0.5	1.01	3.03
Small	4 x ISO 80 02*** Tunnel Sprayer	100	0.5	1.01	3.03
Small	4 x ISO XR80 02* LTI – boom	100	0.5	1.01	4.05
Small	**4 x ISO XR80 02* LTI - boom**	**100**	**1.0**	**1.43**	**5.72**
Large	5 x ISO XR80 02*	100	0.5	1.01	5.06
Large	5 x ISO XR80 02*	200	0.5	1.01	5.06
Large	5 x 65 02*	200	0.5	1.01	5.06
Large	5 x ISO DG80 02*	200	0.5	1.01	5.06
Large	5 x ISO AI110 015*	200	1.0	1.07	5.36
Large	5 x ISO ID90 02**	200	1.0	1.43	7.15
Large	4 x ISO 80 03*** Tunnel spr. + curtain	200	0.5	1.52	6.07
Large	4 x ISO 80 03*** Tunnel sprayer	200	0.5	1.52	6.07
Large	4 x ISO XR80 02* LTI boom	100	0.5	1.01	4.05
Large	**4 x ISO XR80 02* LTI boom**	**100**	**1.0**	**1.43**	**5.72**

*TeeJet Spraying Systems, **Lechler, ***Lurmark. Reference sprayer in bold letters. Tunnel sprayer-Klip Klap from Skovhaave, Denmark, LTI-boom from Agder Produkter, Norway

For large plants the prototype used five nozzles per single row, instead of three nozzles at the earlier stage. The LTI-boom and the tunnel sprayer (Klip Klap) used four nozzles at all stages and the LTI-boom used in addition the same nozzle size. When spraying at growth stage 2, the natural wind speed varied from 0.5 to 1.0 m/s, and the direction equally to that recorded during growth stage 1. The RH varied from 45 to 65% and the temperature from 12 to 21 ºC in the inter row. Therefore, the climatic data range was approximately similar for both growth stages.

All nozzles were from the Spraying Systems Company except the ID90 02 nozzles from Lechler and the ISO 80 02 and 03 nozzles mounted in the tunnel sprayer from Lurmark. To be able to compare the results due to the spraying capacity, all the values were normalised to the same rate as for the reference sprayer, the LTI-boom at 1.0 MPa.

In these drift studies the volume rate per 100 m row was similar for all trials as well as at the two different growth stages according to the experimental set-up using the forward speed to establish the main wind vector. However, in the deposit experiments, the volume rate was doubled at the growth stage 2 vs. growth stage 1 in order to obtain approximately equal leaf deposit according to variations in plant size and leaf area index (Bjugstad and Sønsteby, 2004).

4. RESULTS

Figures 6 – 9 show some results from the experiments.

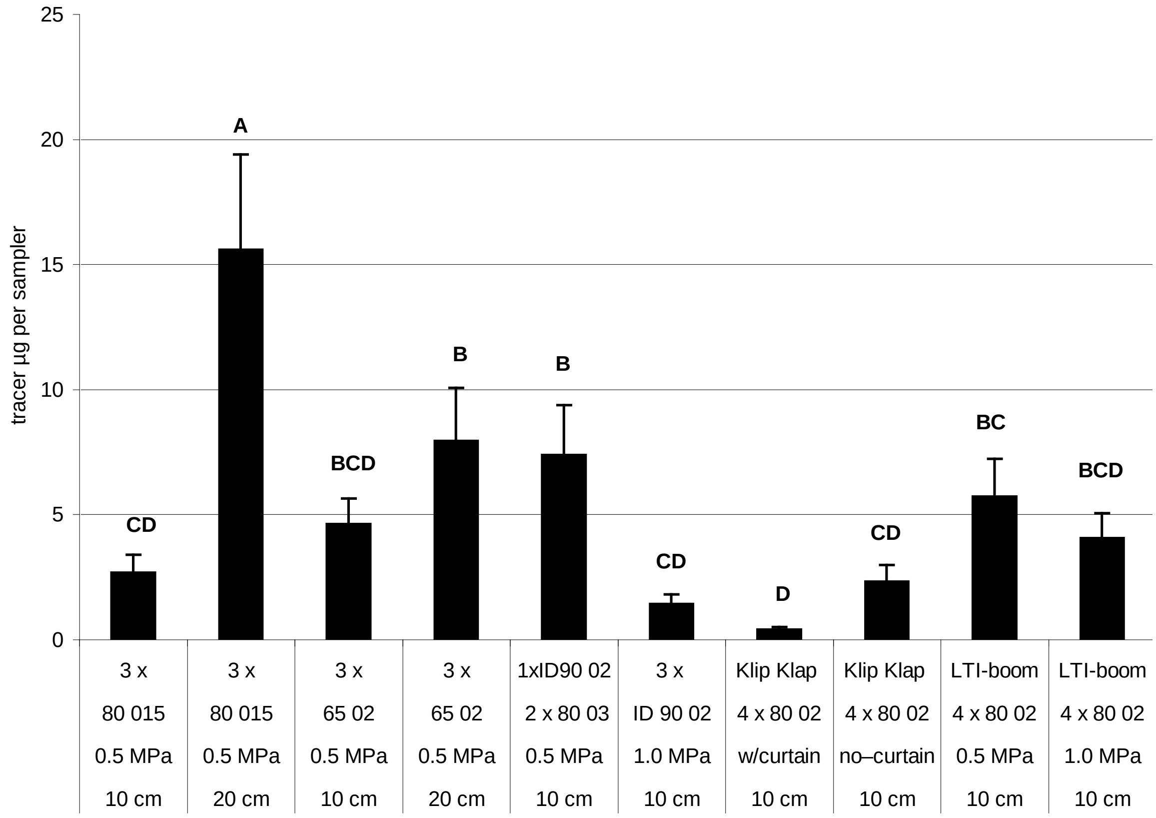


Figure 6. Vertical airborne drift. Average values. Plant stage; small plants. Different letters denote significant differences ($p<0.05$), and vertical error bars denote ± SE.

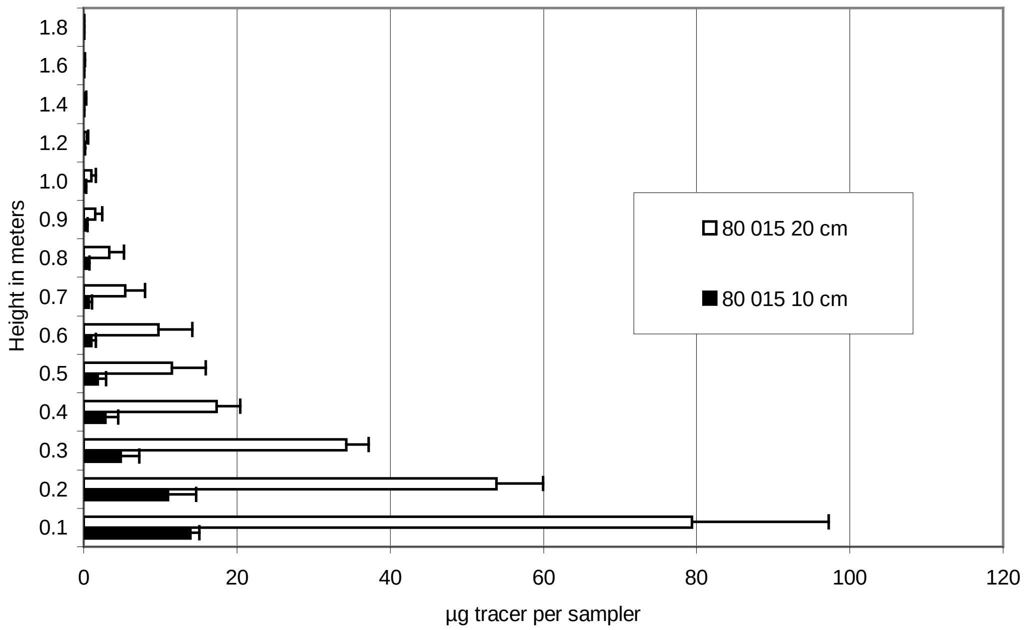


Figure 7. Vertical airborne drift for two nozzle distances. Nozzle ISO XR80 015, 0.5 MPa, 1. stage in May. Horizontal error bars denote ± SE.

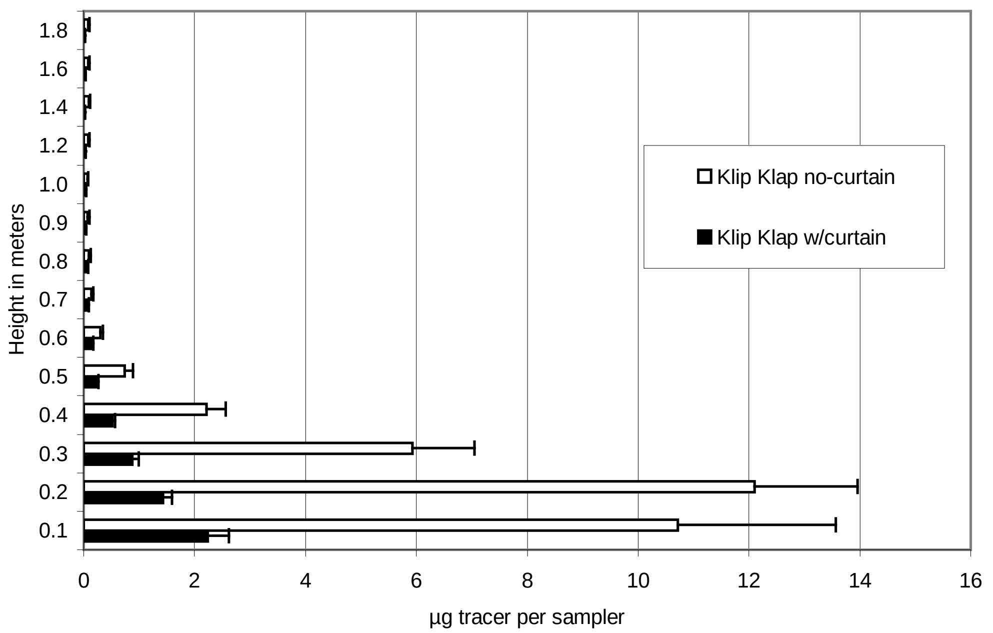


Figure 8. Vertical airborne drift. Tunnel sprayer (Klip Klap) with and without an end curtain. Horizontal error bars denote ± SE. Stage 1 in May.

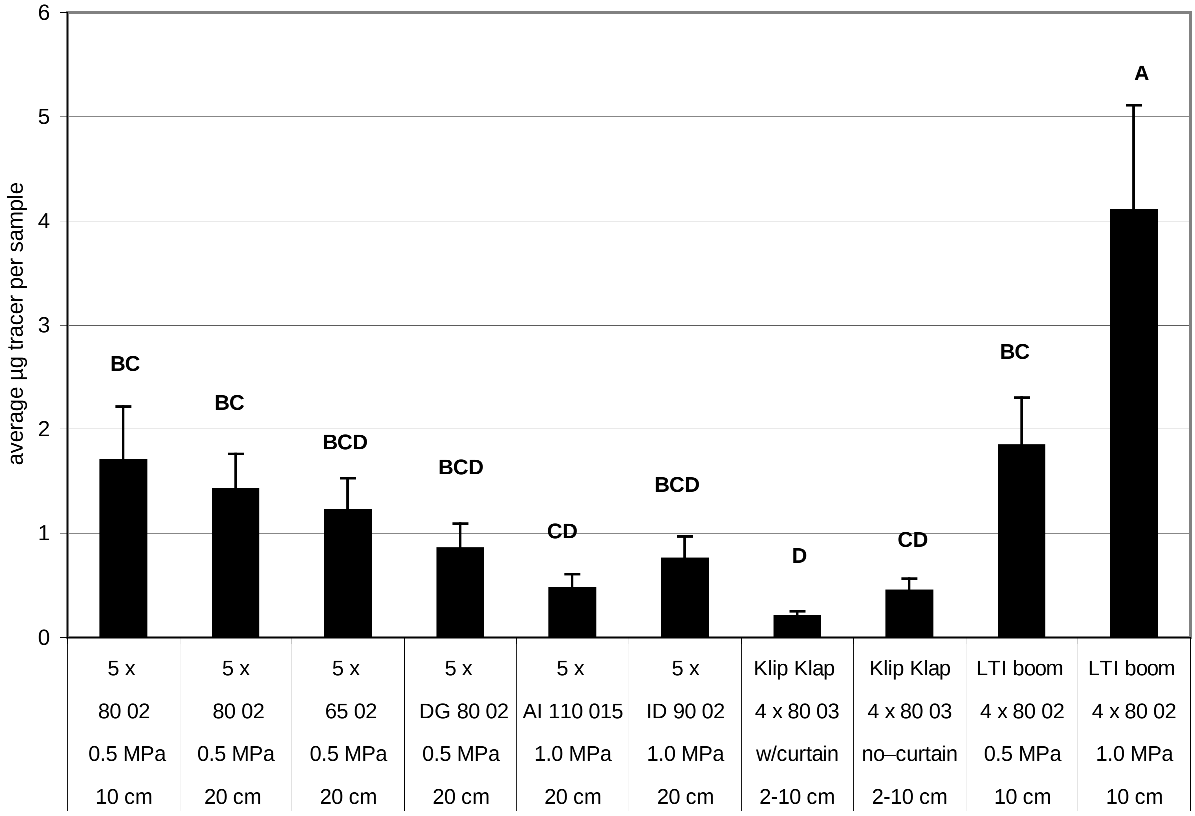


Figure 9. Vertical airborne drift. Average values for Stage 2 in August and large plants. Different letters denote significant differences ($p<0.05$), and error bars denote ± SE.

5. DISCUSSION

5.1 Growth Stage in May

Figure 6 shows the average drift values of calculated amount of tracer per sampler (thread) for all the trials. A reduction in the nozzle distance from 20 to 10 cm gave a significantly ($p<0.05$) lower drift potential for the nozzle size 80 015, but only a tendency for the 65 02 nozzle. This may be explained by the larger proportion of smaller droplets for the wider top angle and smaller nozzle size for the 80 015 nozzle than the 65 02 nozzle.

The 65 02 nozzle gave a tendency of higher drift potential than the 80 015 nozzle at a 10 cm distance. This is hard to explain. However, the difference was not significantly documented.

A combination of using an ID90 02 on the top and conventional nozzles from each side did not reduce the drift significantly compared to the conventional nozzles for the same sprayer.

On the other hand, by using only ID90 02 nozzles at 1.0 MPa, the drift potential was reduced 5.3 times compared to the above mentioned nozzle combination. Air induction nozzles produce larger droplets and thus reduce the risk of drift. The Klip Klap tunnel sprayer with an end curtain gave the lowest drift potential of all the trials.

Figure 7 shows more detailed data of the vertical drift distribution when using the 80 015 nozzles. A distance of 20 cm at the early growth stage caused a significantly higher drift and more droplets were drifting through the higher altitude than at a distance of 10 cm ($p<0.05$). In earlier studies the deposit measurements at this stage also increased when using a distance of only 10 cm compared to 20 cm (Bjugstad and Sønsteby, 2004). Therefore a 10 cm distance is recommended when spraying small plants. However, we recommend a distance of 15 cm in practical use in order to avoid poor distribution due to irregularities according to row spacing and plant size in the field, if the nozzle distance is not to be easily adapted dynamically.

Figure 8 presents the vertical drift from the tunnel sprayer with and without an end curtain. In this study the drift potential from both trials was low, particularly above a height of 0.5 m from the top of the row. The end curtain decreased the drift also in the lower area. The amounts of drift deposits from the tunnel sprayer with and without an end curtain were approx. 10% and 66% of the drift from the reference sprayer (LTI-boom at 1.0 MPa) respectively.

5.2 Growth Stage 2 in August

Average drift values from the application at stage 2 are presented in figure 9. Drift from the 80 02 nozzles tended to decrease when increasing the nozzle distance from 10 to 20 cm from the plant. This could be due to an open leaf structure, because of the late after season spraying time in the middle of August when the leaf density was decreasing. The close nozzle arrangement of 10 cm distance may have increased the kinetic energy of the droplets that could have led to a larger part of droplets to be transported through and outside the canopy. Because of the upright nozzle position for the nozzles from the sides this could cause more droplets into the surrounding air.

The results show a tendency in reduced drift potential when going from conventional nozzles to drift guard nozzles and further on to air induction nozzles at the same nozzle distance of 20 cm. The AI110 015 gave a tendency of lower drift than the ID90 02, both at 1.0 MPa, a pressure commonly used for air induction nozzles.

Also in these experiments the tunnel sprayer (Klip Klap) gave a low drift potential. On average the tunnel sprayer with and without an end curtain resulted in approximately only 4 and 10 % of the drift values from the reference sprayer (LTI-boom at 1.0 MPa). The difference in drift between the tunnel sprayer with and without an end curtain was lower at this growth stage compared to the early stage. This may be caused by the higher filtering effect of the plants at this later stage. This effect may also be studied by comparing all the values in figure 6 against the results in figure 9. On average the reduction in drift potential was approx. 75% at the last stage mainly caused by the increase in the filtering effect.

In this study an increase in pressure from 0.5 to 1.0 MPa increased the drift significantly by a factor of 2.2. This may be due to a higher fraction of small droplets and an increase in the top angle when using a high pressure of 1.0 MPa.

Possible limitations of this sampling method could be; major variations in wind speed and wind direction in the field, small amount of the spray may sometimes pass outside the frame, the samplers could in some extent vibrate vertically during the application. Blank vertical sampling lines proved that the drift was inside the frame during the experiments.

The sampling method described in this paper proved to be successful for a front mounted row crop sprayer. The row was protected from changing wind conditions by a surrounding large hedge row in front of the incoming wind. Wind measurements further out in the field showed large variations in the direction as well as the speed, and speed fluctuations from 1 to over 7-8 m/s were observed. Thus, field studies according to the ISO-standard for this crop and for these circumstances would have been even more time-consuming and larger variations in the measurements would probably have occurred.

6. CONCLUSIONS

The sampling method described in this paper proved to be successful for a front mounted row crop sprayer. The potential drift is mainly dependant of technical parameters and is quickly assessed by this method. Short measuring time ensures more equal experimental conditions and makes it possible to carry out potential drift measurements also for small fields.

The drift potential was significantly reduced compared with the reference sprayer in the following increasing order; by reducing the pressure from 1.0 MPa to 0.5 MPa, using ID nozzles instead of conventional flat spray nozzles, tunnel sprayer without curtain and lowest potential for drift was obtained by using the tunnel sprayer with curtain. Large plants (Stage 2) proved to reduce the risk of drift by 75% compared with small plants (Stage 1).

7. ACKNOWLEDGEMENTS

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