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de Jong, A.; Michielsen, J.M.G.P.; Stallinga, H.; van de Zande, J.C.

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Jong A. de, J.M.G.P. Michielsen, H. Stallinga, J.C. van de Zande
Institute of Agricultural and Environmental Engineering (IMAG), P.O. Box 43,
6700 AA, Wageningen, The Netherlands, Tel: +31-317-476315,Fax: +31-317-425670
a.dejong@imag.wag-ur.nl

SUMMARY

Legislation is introduced by the Dutch government for reduction of the emission of plant protection products to soil, (surface) water and air. A general reduction in spray drift deposition to water surface next to the sprayed field can be achieved by improvements in spray application techniques. One of the techniques to reduce spray drift is to lower the sprayer boom height. In order to reduce the widths of the spray and crop free buffer zones, lowering the boom in combination with the use air-assistance can be a good alternative to reduce the spray drift. A series of field experiments was performed in 1999 to quantify the effect of lowering the sprayer boom height. In these experiments, conventional spraying with sprayer boom heights of 30, 50 and 70 cm above crop canopy was compared with air-assisted spraying at the same three heights above an arable crop. Measurements of spray drift deposition (10 replicates) were done on a bare soil surface downwind of the crop sprayed and perpendicular to the driving direction of the sprayer. A necessary condition to determine the effect of sprayer boom height on the amount of drift is a steady sprayer boom. Steady in such a way that the initial set boom heights can be distinguished under field circumstances. The boom heights were therefore measured in the field.
At a distance of 2-3 meter from the last nozzle perpendicular to the driving direction, a statistical significant difference in reduction in spray drift for conventional spraying of 54% is seen when the boom height is decreased from 70 to 50 cm. When the boom is lowered from 50 to 30 cm the drift is reduced with 56%. Lowering sprayer boom height from 70 cm to 30 cm resulted in an 80% in drift reduction. The use of air-assistance does on average provide an 86% reduction in drift at surface water distance irrespective of boom height.

INTRODUCTION

Legislation is introduced by the Dutch government for reduction of the emission of plant protection products to soil, (surface) water and air. The driftdeposition, when spraying, contributes to the contamination of water surface (MYCPP, 1991 and VWS/VROM/LNV, 2000). Therefore spray free and crop free bufferzones are introduced, to minimise the risk. Especially aquatic life is vulnerable to the toxic contents of plant protection products. Field measurements of spray drift from boom sprayers operating over arable crops have shown that drift increases with increase in wind speed, boom height, forward speed, and when a high proportion of the spray is produced in fine drops (<100µm in diameter). The need to make timely applications of pesticide involves operating with high work rates. This often involves the use of wide booms and low-volume rates involving fine sprays. All of these trends increase the risk of spray drift (Zande et al., 2000).
A general reduction in spray drift deposition to water surface next to the sprayed field can be achieved by improvements in spray application techniques. One of the techniques to lower spray drift is to decrease the sprayer boom height.

A mathematical model was developed to predict spray drop trajectories in the drifting spray plume downwind of the application (Holterman et al., 1997). This model shows a correlation between sprayer boom height and drift, the lower the boom height the lower the drift. A series of field experiments was performed in 1999 to quantify the effect of lowering the sprayer boom height. In these experiments, conventional spraying with spray boom heights of 30, 50 and 70 cm above the crop was compared with air-assisted spraying at the same three heights above an arable crop. Measurements of drift deposition (10 replicates) were done on a bare soil surface downwind of the crop sprayed and perpendicular to the driving direction of the sprayer. A necessary condition to determine the effect of sprayer boom height on the amount of drift is a steady sprayer boom. Steady in such a way that the different initial set boom heights can be distinguished under field circumstances. The boom heights were therefor measured in the field.

MATERIALS & METHODS

Measurement of spray drift

A series of field experiments were performed in 1999 to quantify the effect of lowering the sprayer boom height on drift deposition adjacent to a sprayed crop. In these experiments, conventional spraying at spray boom heights of 30, 50 and 70 cm above a 50 cm crop were compared. Also the effect of air-assisted spraying on the drift deposition was evaluated for the same three boom heights. All tests were done in 10 replicates. During a drift measurement the field was sprayed over 50 m in length and 24 m wide with a Hardi Twin Force commander 2000, using XR110-04 nozzles (Teejet) and applying 300 l/ha. The spraying was done with water to which the dye Brilliant Sulfo Flavine (BSF, 2 g/l) and a surfactant (Agral™, 1 ml/l) were added.

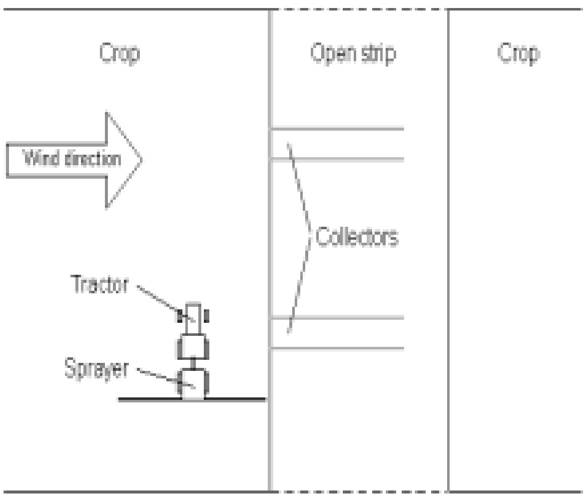

Figure 1 Schematic layout of the sprayed field with a open strip to facilitate the collector placement.

The drift deposition was measured with collectors at different positions next to the sprayed field. Two rows of collectors (strips with filter cloth of 50×10 cm and 100×10 cm) were placed perpendicular to the driving direction at distances of 0.5-1, 1-1.5, 1.5-2, 2-3, 4-5, 5-6, 7.5-8.5, 10-11 and 15-16 m from the last nozzle. At a distance of 5.5 m from the last nozzle a pole was erected with two lines with bulb shaped collectors at heights of 0, 1, 2, 3 and 4 m above the surface layer. These collectors were catching the drift in the air. Also filter cloth was placed at crop height during spraying without air-assistance, to check the actual sprayed amount. After spraying the collectors where gathered and rinsed with water to dissolve the BSF. The concentration of BSF was measured with a fluorimeter (Perkin Elmer LS 30). This concentration was then recalculated as volume of the sprayed amount per surface and expressed in $\mu l/cm^2$. The drift is ultimately expressed as the percentage of the applied amount. The measurements with and without air-assistance for the same boom height were done directly after each other at two places with two strips of collectors as seen in Figure 1. When the boommovement measurements were incorporated in the drift measurements the

spraying was done on one place only. So the field influences on the boommovement remained the same.
Due to the weather circumstances, especially the wind direction was not optimal, not all measurements were done in the designated potato crop. To make sure the wind direction was as perpendicular as possible, the measurements were also done in a sugarbeet crop (4 replicates) and yellow mustard crop (4 replicates). In total 10 replicates were done.
Different influences on drift and its interactions were calculated for during the statistical analysis of the measured results. The difference between objects (boom height and air-assistance) were tested with a confidence interval of 5%. Due to the kind of distribution (quasi binomial) the analysis was performed with the Genstat procedure IRREML (Keen et al., 1998).
In figure 2 is a schematic view given of a ditch next to a crop for an average Dutch field, as can be seen the distance of the water surface to the outside of the crop is 2.25 to 3.25 meters. The last nozzle of the sprayer was 0.25 m outside the last crop row, the distance of the water surface to the last nozzle was 2 to 3 meters. The amount of spray drift collected with the collectors at this distance is the most important evaluation figure. For the ditch with part of the side banks an evaluation distance from 1 to 4 meters was taken. Drift deposition was evaluated for these two zones next to the field.

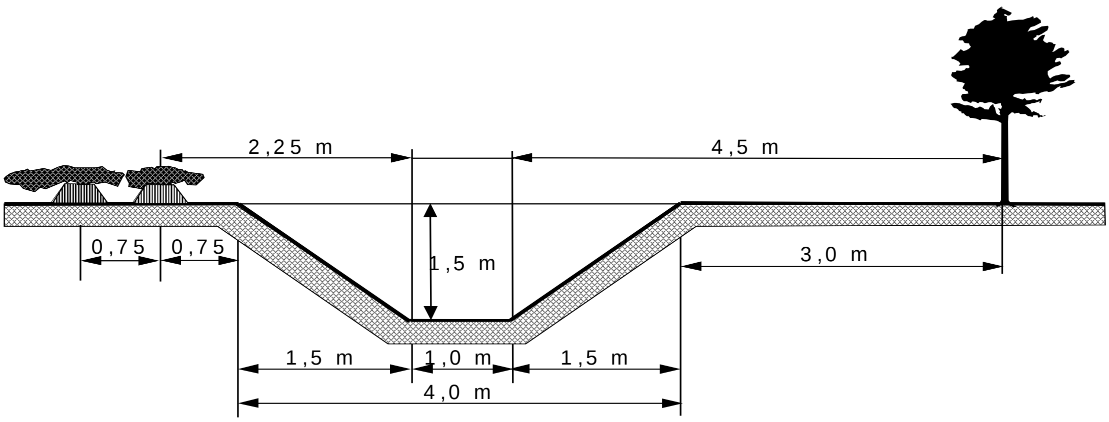

Figure 2 Schematic layout of a ditch, with a potato crop on the left, in this situation the water surface is on 2 meters from the last nozzle at the bottom of the ditch.

Measurement on the sprayer boom movements

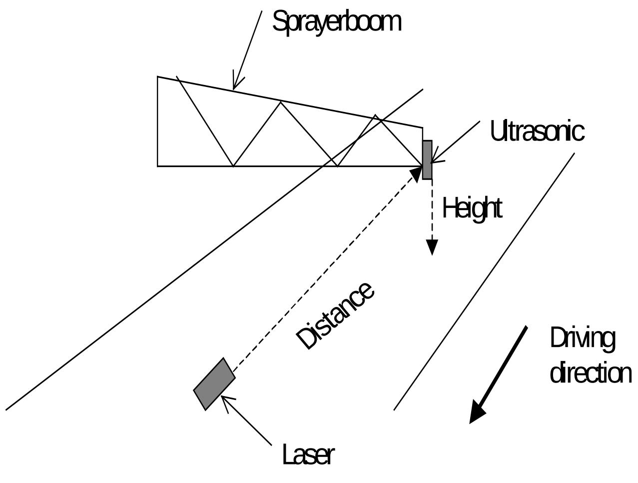

Figure 3 Schematic view of the system with the laser and ultrasonic sound system, when measuring in the field.

A necessary condition to determine the effect of sprayer boom height on the amount of drift is a steady sprayer boom. Steady in such a way that the different initial set boom heights can be distinguished under field circumstances, thus even with the disturbances when riding through a crop. Extra care was being taken to make sure that the boom was not moving extraordinary at the site where the collectors were placed. When the boom moved too much, the collectors were moved to a spot with less boommovement. To distinguish the initial set boom heights these were checked with a system consisting of a laser distance indicator and an ultrasonic sound height indicator Figure 3. The ultrasonic sensor was connected at the end of the sprayer boom, to measure over the open strip where the drift collectors were placed. The system checked every 0.1 second the distance and height of the boomtip in the field. The height and the distance, together with the time were recorded online. This data was used for further analyses of the sprayer boom movement under field circumstances. Boommovements could be divided into two basic movements: the vertical plane and in the horizontal plane. The first is the deflection of the boom according to the initial boom height (rolling or dancing). The second movement was calculated as the deflection of the boom in respect to the average driving velocity of the tractor and sprayer (yawing or jolting).

Weather conditions

During the field measurements: temperature, relative air-humidity, wind direction and wind speed were recorded. On average the wind speed was 3.1 m/s, the temperature 14° C and the relative air-humidity 81%. The wind direction had an average of 17.5 degrees out of square with the driving direction, with 30 degrees as an absolute maximum.

RESULTS

Drift to the ground next to the field

Figure 4 shows the measured drift deposits expressed as a percentage of the applied amount spray fluid. In both cases, conventional and air-assisted, drift depositions decreased with increasing distance to the last nozzle, lowering the boom height reduced the drift. A comparison of the two charts in figure 4 shows that the average drift for a specific boom height is lower with the use of air-assistance.

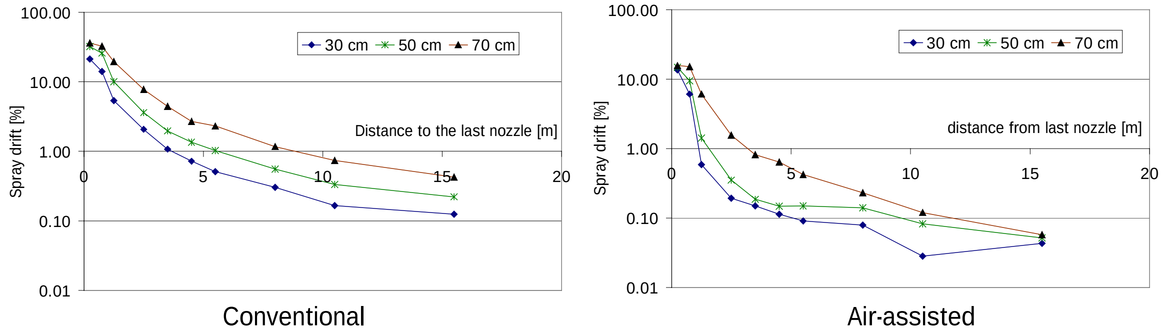

Figure 4 Drift (expressed as percentage of the spray dose on a logarithmic scale) at different distances from the last nozzle for three heights of the sprayer boom above the crop. Left figure for conventional spraying, right figure for air-assisted spraying

In table 1 the average driftpercentages at the strip of 2-3 m and 1-4m from the last nozzle are given. From table 1 it can be concluded that when not using air-assistance there is a significant difference in drift between the boom heights. There is always a significant difference between a boom height of 70 cm and the 30 or 50 cm boom heights. As already in the charts of figure 4 can be seen, a lower boom height gives less drift. When air-assistance is used there is no significant difference between 30 and 50 cm boom height for the 2-3 m distance. Table 1 shows that the use of air-assistance significantly decreases the drift for every boom height. Remarkable is the absence of a significant difference between the sprayer boom height of 30 cm without air-assistance and 70 cm with air-assistance.
On average the same conclusions can be drawn for the 1-4m evaluation distance as for the 2-3m zone. However, also significant distinction between 30 and 50 cm boom height with air-assistance can be made. No significant differences could be found between 30 cm boom height with air-assistance and 50 and 70 cm without air-assistance.

Table 1: The average measured amount of spray drift for different boom heights, with or without air-assistance at two evaluation zones from the last nozzle.

Height (cm)	Air	Evaluation zone*	
		2-3m	1-4m
70	no	7.78[d]	12.75[e]
"	full	1.55[b]	4.31[c]
50	no	3.61[c]	7.85[d]
"	full	0.35[a]	1.99[b]
30	no	1.59[b]	3.32[bc]
"	full	0.17[a]	1.06[a]

** A different letter in a column (at an evaluation distance) means there is a significant difference ($\alpha<0.05$) between the heights and air-assistance.

Driftreduction
To quantify the effect of driftreduction for the different boom heights, the figures are calculated as percentages of reduction according to the standard boom heights of 70, 50 and 30 cm. Reductions compared to these boom heights for with and without air-assistance spraying are calculated and presented in table 2.

Table 2: The driftreduction percentages for the different boom heights, with or without air-assistance on the evaluation zones 2-3 m and 1-4 m from the last nozzle. The reduction is expressed to 70, 50 or 30 cm without air-assistance.

Boom height (cm)	Air	Drift reduction to boomheight on evaluation zones					
		to 70 cm		to 50 cm		to 30 cm	
		2-3m	1-4m	2-3m	1-4m	2-3m	1-4m
70	no	-*	-*	-116	-62	-389	-284
"	full	80	66	57	45	3	-30
50	no	54	38	-**	-**	-127	-136
"	full	96	84	90	75	78	40
30	no	80	74	56	58	-***	-***
"	full	98	92	95	86	89	68

Table 2 shows that the lower the boom, the more the drift is reduced. A negative percentage in the table means more drift relatively to the standard. The reduction effect for boom height or air-assistance for the ditch (1-4 meter) is on average lower than at water surface (2-3 meter) level. Highest spray drift reduction is with 30 cm boom height and the additional use of air assistance compared to 70 cm boom height conventional spraying. Spray drift reduction is 98 % for with 30 cm boom height and use of air assistance and 96% for 50 cm boom height and use of air assistance. 50 cm boom height compared to the 30 cm boom height without air-assistance shows almost 60% reduction in drift.
The reduction effect of air-assistance at a specific boom height is lowest for 70 cm boom height; on water surface level the use of air-assistance reduces drift with 80%. For 50 cm boom height this reduction is 90% and for 30 cm 89%. For the ditch (1-4m evaluation distance) these reduction percentages are lower resp.: 66, 75 and 68%.

Airborne drift
In table 3 the average values over the measured heights in the air and the reductions in drift are given.

Table 3: Average measured airborne drift (with and without air-assistance) per sprayer boom height, as a percentage of the applied dose. And driftreduction compared to conventional spraying at different heights.

Boom height (cm)	Air-assistence	Average drift (%)*	Drift reduction		
			to 70 cm (%)	to 50 cm (%)	to 30 cm (%)
70	no	3.10^{c}	-	-82	-138
"	full	0.27^{a}	91	84	79
50	no	1.70^{b}	45	-	-31
"	full	0.22^{a}	93	87	83
30	no	1.30^{b}	58	24	-
"	full	0.15^{a}	95	91	88

* A different letter indicates that there is a significant difference ($\alpha<0.05$) between the average drift values.

From table 3 it can be concluded that lowering the sprayer boom from 70 to 50 cm (without air-assistance) significantly reduces the airborne drift. When the sprayer boom is lowered from 50 cm to 30 cm, the airborne drift decreases but not significantly. The use of air-assistance shows no significant difference in drift between the boom heights. When 70 cm boom height conventional spraying is compared to conventional spraying at 50 and 30 cm the drift is reduced with resp. 45 and 58%. Conventional spraying at 70 cm boom height compared to air-assistance spraying at 70, 50 and 30 cm, reduces drift resp. with 91, 93 and 95%. The drift reductions calculated for airborne drift show the same tendency as for the drift to the ground.

Boommovement (rolling or dancing)

Rolling or dancing means a movement of the boom in a vertical plane. As an example of this rolling in figure 5 a single measurement is shown for the three boom heights (resp. 30, 50 and 70 above the crop canopy) and with or without air-assistance. The measured heights of the boomtip to the soil are plotted against the travelled distance. When the sprayer boom would not have moved, only straight lines on the set heights would be plotted in the figure. The maximum deflections of the boom are not over ± 20 cm in relation to the initial boom heights. As measurements were done at the boomtip on the outside of the sprayer boom the plotted data shows the extremes. The height of the crop canopy was on average 55 cm, so the 30 cm boom height was always above the crop.

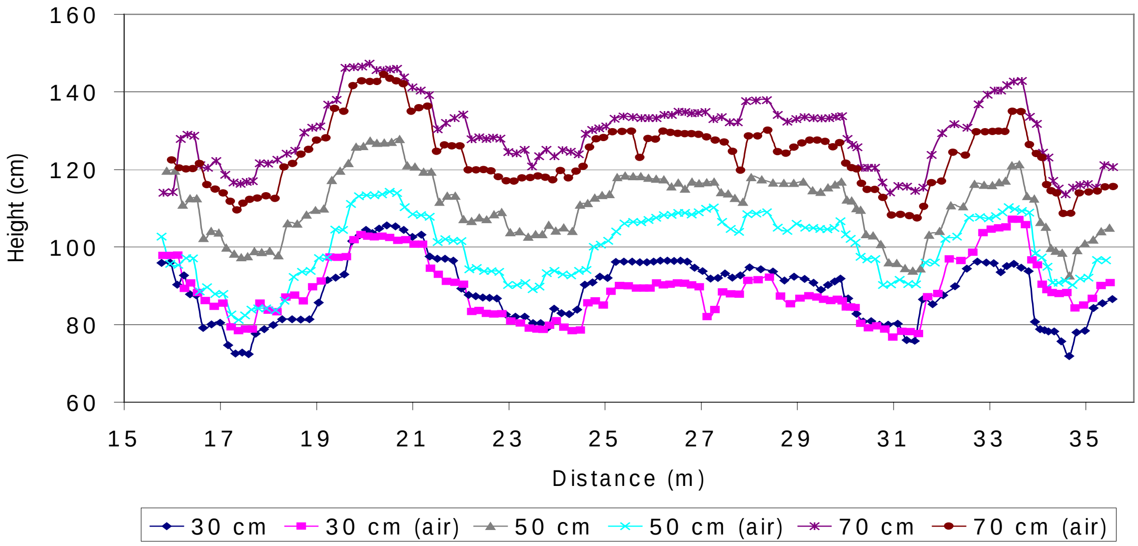

Figure 5 Typical boomtip movements of the sprayer under field circumstances. The measured boom heights to the ground plotted against the travelled distance, for the three boom heights with and without air-assistance.

The chart in figure 6 shows the average curve of the curves in figure 5 and the deviations of the single curves on this average. The average is around the same height as the 50 cm curves in figure 5. Thus the deviations of the 50 cm boom heights oscillate around zero, the deviations of the 70 cm are on the expected average plus 20 cm and for 30 cm around minus 20 cm. Except from set boom height little deviations do occur between boom heights and air-assistance compared to the average vertical movement. This average vertical movement curve can therefore be seen as a characteristic curve describing the influence of the sprayer (and soil and driving conditions) on the vertical movement of the sprayer boom.

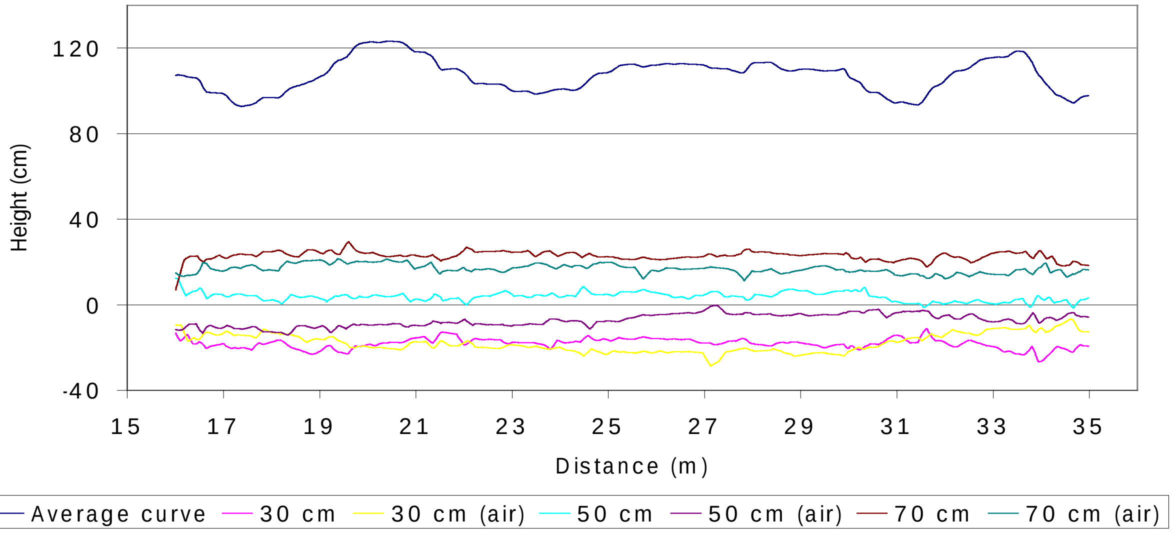

Figure 6 Average sprayer boom height above soil surface (top) and deflections on this average for the individual sprayer boom heights (conventional and with air-assistance, plotted around zero) presented to travelled distance.

Boommovement (yawing or jolting)

Yawing or jolting means that the boom is moving in a horizontal plane. Thus describing the deflection of the boom to the ideal uniform driving speed of the tractor in the field. This phenomenon has a large effect on the spray distribution (Sinfort et al., 1994). In figure 7 the horizontal deviation of the boomtip is plotted against the travelled distance of the sprayer. The driving direction in this figure was from right to left. Figure 7 shows a maximum deflection of ± 20 cm. After a while those peaks are damped to ± 10 cm. As for the vertical movements no influences of boom height or air-assistance on the form of the curve can be seen, the form remains the same. Remarkable for figure 5, 6 and 7 is that the horizontal and vertical movements of the boom takes place at the same measured distances, the peaks and valleys are on the same measured distances. So the disturbance in the field through bumps or pits do cause a vertical and a horizontal movement at the same time.

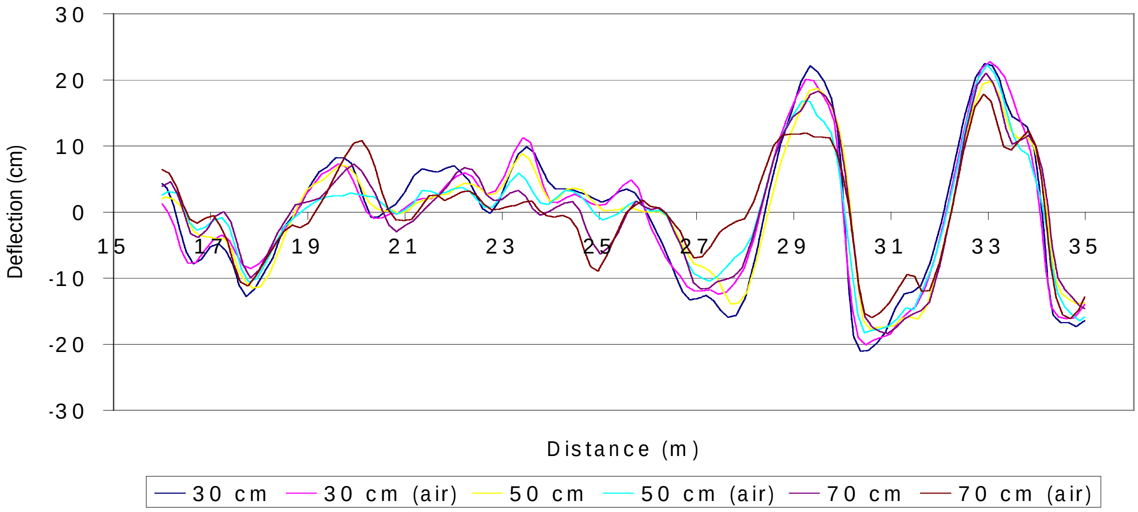

Figure 7 Deflections of the sprayer boom in the horizontal plane (yawing or jolting), expressed as the deflection of the boom to the average driving speed on the travelled distance.

DISCUSSION

The sprayer boom width was 24 meter, so a vertical deflection of 20 cm over 12 meter length (half the boom) is relatively small. When this 12 meter is regarded stiff and the middle of the sprayer has a zero deviation then large parts of the sprayer boom will maintain the correct initial height.
After statistical analyses ($\alpha<0.05$) no difference in conclusions could be found between the different crops. Although in different crops the place of the last nozzle changes due to different row distances. This can influence the measured drift on the first measured strips, because when the nozzle is over the edge of the crop it sprays directly on the strip. There is no crop to catch the droplets, so they easily become airborne. The measured differences between crops were also caused by different weather circumstances, because the measurements were done over several days.
The lowering of the boom to 30 cm can cause problems with the evenness of the spray distribution when the nozzle distance on the sprayer boom remains 50 cm.
The influence of a horizontal movement on spray drift is not known. A movement can have a negative effect on the entailment of the smaller droplets when following in the slipstream of the larger ones. But increasing wind velocity (as of higher forward speeds when the boom moves in the driving direction) increases the removal of drops and increases drift (Murphy et al., 2000).
A significant effect is found of boom height on the amount of drift. A vertical movement of the sprayer boom can cause more drift. With this type of movements at least one side of the sprayer will be higher then the initial set height and cause more drift. This effect will not be equalised by the lower other side of the sprayer boom, because the absolute levels in spray drift differ. For example the absolute difference in drift between 70 and 50 cm boom height is larger then between 50 and 30 cm boom height.

CONCLUSION

Lowering the height of the sprayer boom significantly reduces spray drift. The additional use of air assistance on the sprayer reduces the spray drift for every boom height. At a distance of 2-3 meter from the last nozzle, a statistical significant difference in reduction in spray drift for conventional spraying of 54% is seen when the boom height is decreased from 70 to 50 cm. When the boom is lowered from 50 to 30 cm the drift is reduced with 56%. And when the boom is changed from 70 cm to 30 cm an 80% in drift reduction is shown. The use of air-assistance does on average provide an 86% reduction in drift at water surface level for each boom height. The spray drift level for conventional spraying at 30 cm boom height is the same as for 70 boom height with air-assistance.
Although a sprayer boom always makes vertical movements during spraying, it is possible to significantly distinguish the levels of spray drift for the different boom heights. The measured boommovements indicate that the sprayer boom moves between small margins of the initial set boom heights during spraying in the field. The deflections both in the vertical as in the horizontal plane occur at the same spots unrelated to boom height or whether the air-assistance is used or not.

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