Environmentalist (2008) 28:9–17
DOI 10.1007/s10669-007-9036-5

Spray techniques: how to optimise spray deposition and minimise spray drift

Jan C. van de Zande · J. F. M. Huijsmans · H. A. J. Porskamp · J. M. G. P. Michielsen · H. Stallinga · H. J. Holterman · A. de Jong

Abstract A summary is given of research within the field of application technology for crop protection products for the past 10 years in The Netherlands. Results are presented for greenhouse, orchard, nursery tree and arable field spraying for the typical Dutch situation. Research predominantly focussed on the quantification of spray deposition in crop canopy and the emissions into the environment, especially spray drift. The risk of spray drift is related to defined distances and dimensions of the surface water adjacent to a sprayed field. Spray deposition and spray drift research was setup in order to identify and quantify drift-reducing technologies. Results are presented for cross-flow sprayers, tunnel sprayers and air-assisted field sprayers. For field crop spraying with a boom sprayer the effect of nozzle type on spray deposition in crop canopy and spray drift is highlighted both with a modelling approach as based on field experiments. The use of spray drift data in regulation is discussed. A relation between spray deposition and biological efficacy is outlined for drift-reducing spray techniques. The effect of spray drift-reducing technologies in combination with crop- and spray-free buffer zones is outlined. It is concluded that spray technology plays an important role to minimise spray- and crop-free buffer zones, and to maintain biological efficacy and acceptable levels of ecotoxicological risk in the surface water.

1 Introduction

1.1 Background

The Multi Year Crop Protection Plan (MYCPP 1991) of the Dutch government formulated objectives for a reduction in plant protection products to be used and for an application practice for these products, which is safe and more compatible with the environment. The emissions of plant protection products to soil, (surface) water and air should be reduced. A general reduction in spray drift to surface water next to the sprayed field can be achieved by improvements in spray application techniques. For the last 10 years an intensive measuring programme has been performed, especially on spray drift. The research programme consisted of laboratory measurements, field experiments and computer modelling. A system analysis approach was developed to divide the research into processes of parts important for spray deposition and drift. A division was made in the scale of the processes: the field, the plant and the leaf level. Within these fields subjects of research are: the nozzle (drop sizes, spray quality, driftability), sprayer boom movement and boom height (drop trajectory), sprayer outline and additional drift-reducing technology on it, the crop type (height, density and the placement of the last nozzle to the edge of the crop), the field layout and the place of the surface water. A stepwise approach was chosen to lower drift. For arable crop spraying these steps were: air assistance or shielding sprayer booms on a field sprayer, a tunnel sprayer, sprayer boom height and nozzle type.

The results of this research are incorporated into policies and used by water authorities and authorities for the approval of crop protection products. Furthermore, results are used by farmers, by the agricultural supply industry in

---

J. C. van de Zande (✉) · J. F. M. Huijsmans ·
H. A. J. Porskamp · J. M. G. P. Michielsen · H. Stallinga ·
H. J. Holterman · A. de Jong
Institute of Agricultural and Environmental Engineering,
IMAG B.V, P.O. Box 43, 6700 AA Wageningen,
The Netherlands
e-mail: jan.vandezande@wur.nl

the development of new spray techniques and the agrochemical industry. Different aspects will be highlighted in this paper, both for orchard spraying, nursery tree spraying as for arable field spraying. Results from the research programme are summarised.

1.2 Research approach

Crop protection products must be applied with utmost efficiency to prevent environmental effects and save costs. At IMAG the technical research towards these objectives combines field and laboratory research and model studies of the spraying process. The relationship between biological effectiveness and environmental impact is quantified. The research contributes to a further optimisation of the spraying process. By linking the results of experiments with model results, the generally variable field measurements can be standardised. The available measuring techniques, or new ones developed, are used to evaluate and initiate new developments in spraying technology under laboratory and field conditions. Field, laboratory and model research results are combined to determine the effect of factors such as spraying technique, crop and weather conditions on the spraying process. The spraying process is analysed in a step-wise approach: how is a droplet created, how is it transported from nozzle to target, how does the droplet spread on its target.

The spraying technique can control and optimise this process to achieve maximum effectiveness (spread and deposition on the crop), minimum emission (to soil surface and deposition on water due to drift) and minimum exposure to the user. The measuring methods and techniques required are being developed. Components of the spraying process are quantified in field and laboratory research. The integration of knowledge will result in models describing components of the process, and in the development of improved spraying techniques.

2 Materials and methods

2.1 Modelling

Spray quality and driftability are two important nozzle parameters in spray technique. The spray quality (is of importance for crop coverage) depends on nozzle type, nozzle size and spray pressure. Drop size, drop speed and drop direction in the spray fan influence driftability. Through a combination of laboratory measurements and computer modelling a driftability classification system can be developed. With a PDPA-laser (Aerometrics; Phase Doppler Particle Analyser), spray quality and drop speed are measured. These data are used as input for the IDEFICS spray drift model (Holterman et al. 1997), calculating spray drift deposits downwind of the sprayed field. Spray drift is calculated for the zone 2.125–3.125 m from the last nozzle. In most cases this is the surface water area of the ditches adjacent to a potato field.

2.2 Field measurements

The developed methodology to classify spray nozzles for driftability holds only for conventional use of nozzles on a sprayer boom. Extension of the classification of driftability of nozzle types in combination with air assistance, shielding, etc. on field sprayers is carried out in field measurements of spray drift.

In a series of field experiments air-assisted spraying was compared with conventional spraying in a potato crop during the growing season. The effect of low-drift nozzles on spray drift was also quantified, as well as the effect of a no-spray buffer zone. Measurements were done on a bare soil surface and in a ditch, downwind of the crop.

Spray drift measurements were carried out by adding the fluorescent dye Brilliant Sulfo Flavine (BSF) to the spray agent and placing collectors in and outside the field. The swath-width sprayed was at least 18 m. The length of the sprayed track was at least 50 m. A minimum of 10 replications were made in time and place along the edge of the field during the growing season. The distance of the last downwind nozzle to the edge of the field (the last crop leaves) was determined. Measurements of spray drift were always compared to a reference situation i.e. field sprayers applying a volume rate of 300 l/ha with a Medium spray quality. In case of air assistance, nozzles were kept vertical and air velocity was set to the maximum capacity of the fan.

Ground deposit was measured on horizontal collection surfaces placed at ground level in a double row downwind of the sprayed swath. When measuring field sprayers the collectors were placed at distances 0–0.5, 1–1.5, 1.5–2, 2–3, 3–4, 4–5, 5–6, 7.5–8.5, 10–11, 15–16 m from the last downwind nozzle. Collectors used were synthetic cloths with dimensions of 0.50 × 0.08 m and 1.00 × 0.08 m.

Airborne spray drift was measured at a distance of 5.5 m from the last downwind nozzle. The collection of airborne spray was done on two separate lines with attached collectors at 0, 1, 2, 3 and 4 m height. Collectors used were spherical synthetic cleaning pads (diameter 0.08 m). Drift for orchard and nursery tree sprayers was measured in a similar way, with collector distances adapted for the typical field layout. After spraying, the dye was extracted from the collectors. The rate was measured by fluorimetry and expressed per surface area of the collector. The spray drift was expressed as percentages of the application rate of the sprayer (spray dose).

Meteorological conditions during spray drift measurements were recorded. Wind speed and temperature were recorded at 5 s interval at 0.5 m and 2.0 m height, using cup anemometers and Pt100 sensors. Relative humidity was measured at 0.5 m height and wind direction at 2.0 m height. Statistical analysis of the data was done using analysis of variance (ANOVA 5% probability).

3 Spray drift

3.1 Modelling

In The Netherlands and other countries the term ‘‘low-drift’’ spray nozzles has been in use for quite a while. To define the terminology used with respect to low-drift spray nozzles, a classification system of drift sensitivity was developed. With this classification system the nozzles can then be classified into drift-reduction classes (0, 25, 50, 75 and more than 90% drift reduction) compared to a reference nozzle BCPC Fine/Medium (Southcombe et al. 1997) in a reference situation. Classification is performed at a wind speed of 3 m/s, a crop height of 50 cm and a sprayer boom height of 50 cm above crop canopy. Nozzle–pressure combinations are classified accordingly. It was shown that the combination of nozzle type, nozzle size and spray pressure (Table 1) defines the spray drift (Porskamp et al. 1999b).

3.2 Modelling sprayer boom movement and spray deposition

To record the spray boom motions in the field, a measurement system was developed which records the horizontal and the vertical motions simultaneously. The system is based on laser distance measurement for motions in the horizontal plane and ultrasonic height measurement for those in the vertical plane. Measurements in the field and on a conditioned track (bump strip) proved that differences in setting and design of spray boom suspension systems and balancing systems can be quantified quite accurately. A distribution model (DEPOFIX) has been developed to assess the distribution pattern underneath a moving sprayer boom. Data from field measurement of boom movements can be used directly as input in the distribution model (DEPOFIX). The effect on the distribution of the spray liquid in the basal area can be calculated. Under- and overdoses of 40% and 300% of the desired dose (100%) were found to occur.

For the further development of the DEPOFIX model for calculating the distribution of spraying fluid in the basal area under a moving spray boom, measurements were performed on the spraying track at the laboratory. The

Table 1 Classification of nozzle–pressure combinations for spray quality and driftability. Spray quality is classified according to BCPC. Spray drift reduction is quantified with the threshold nozzle Fine/Medium (Lurmark 31-03-F110 @ 3 bar) as a reference (Porskamp et al. 1999b)

Manufacturer	Nozzle type	Pressure (bar)	Spray quality	Drift reduction class
Delavan	LF-110-01	4.5	Very fine/fine	–90
Lurmark	**31-03-F110**	**3.0**	**Fine/medium**	**0**
Lechler	LU 120-06S	2.0	Medium/coarse	50
Teejet	8008 VS	2.5	Coarse/very coarse	75
Teejet	8015 SS	2.0	Very coarse/extra coarse	90
Albuz	ADE3 orange	1.5	Coarse	75
Albuz	ADE3 orange	3.0	Medium	50
Albuz	ADE3 orange	5.0	Medium	25
Lechler	ID 120-02	3.0	Extra coarse	75
Lechler	ID 120-02	5.0	Very coarse	75
Lechler	ID 120-02	7.0	Coarse	50
Teejet	TT11004	1.5	Very coarse	75
Teejet	TT11004	3.0	Coarse	50
Teejet	TT11004	5.0	Medium	–25
Teejet	DG11002	3.0	Medium	25
Teejet	DG11004	3.0	Coarse	50
Teejet	XR11002	3.0	Fine	–90
Teejet	XR11004	3.0	Medium	0
Teejet	XR11008	3.0	Coarse	50

effects of nozzle type, spray boom height, spray boom motion, driving speed and the travel of the spray boom (amplitude) were studied (de Jong et al. 2000b).

4 Field experiments

4.1 Arable crops

4.1.1 Crop-free buffer zone

In the period 1992–1994 (Porskamp et al. 1995) spray drift was assessed for a field sprayer applying spray volumes of 150 l/ha and 300 l/ha, respectively with a Fine and a Medium spray quality (Southcombe et al. 1997). Sprayer boom height was set to 0.7 m above the canopy of the potato crop. Within this volume range the spray quality did not significantly affect the drift deposition in the experiments. Spray drift deposition on the distance 2.25–3.25 m from the last potato-row was on average 5.3% for both nozzle types sprayed conventionally. Compared to conventional spraying, a field boom sprayer with air assistance achieved a 50% reduction in spray drift on the soil surface at the same downwind distance. Increasing the distance from the crop boundary, and therefore the last nozzle to the surface water zone, by means of a non-cropped spray-free zone of 2.25 m (three potato ridges) reduced the deposition by 70% on the surface water zone (Porskamp et al. 1995).

4.1.2 Spray volume, nozzle type and air assistance

In 1997, 1998 and 1999 field tests on spray drift were performed to quantify the effect of two spray volumes using “low-drift” nozzle types and air assistance (Van de Zande et al. 2000b). Spray drift was quantified for a series of low-drift nozzle types all applying a spray volume of 150 l/ha and 300 l/ha. With identical travelling speed, sprayer boom height (0.5 m above crop canopy) and liquid pressure (3 bar) the nozzle types: standard flat fan (XR), drift guard (DG), anvil flatfan (TT) and two types of injection nozzles (ID and XLTD) were evaluated in the field. All nozzles were used in a conventional way and with the use of air assistance (Hardi Twin, full capacity - nozzles kept vertical). Canopy height of the potato crop was 0.5 m. Results (Figs. 1, 2) show that the terminology “low-drift nozzle” needs further specification. From the experiments it became clear that within the group of low-drift nozzles a ranking by level of drift reduction is preferable. The comparison with a standard sprayer-nozzle configuration is of value, also for comparison of the results with other drift experiments.

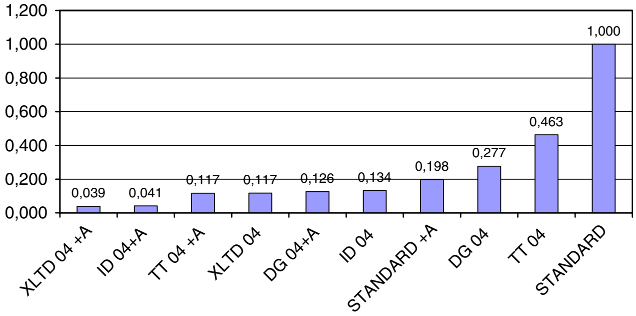

Fig. 1 Relative spray drift deposition on 2–3 m from the last nozzle for different low-drift nozzles and air assistance (+A) when spraying potatoes with a spray volume of 300 l/ha. Standard nozzle type is XR11004 (=1)

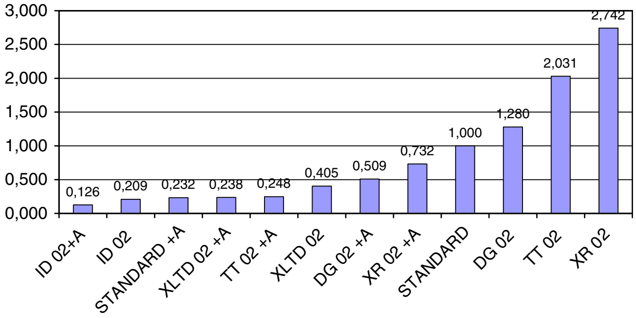

Fig. 2 Relative spray drift deposition on 2–3 m from the last nozzle for different low-drift nozzles and air assistance (+A) when spraying potatoes with a spray volume of 150 l/ha. Standard nozzle type is XR11004 (=1)

Although with all nozzles a spray volume of either 150 l/ha or 300 l/ha was used, the difference in the range of droplet sizes resulted in drift reductions up to more than 95% when compared to a XR11004 nozzle (Van de Zande et al. 2000b). The terminology ‘‘low-drift’’ nozzle therefore needs further specification.

Because of the use of air assistance the reduction of spray drift was independent of the nozzle type, at around 70% (except for the ID12002 and the XLTD02).

4.1.3 Band spraying

The drift caused by the use of a band sprayer was recorded during field measurements. The sprayings were carried out in sugar beet and maize crops with row spacings of 50 cm and 75 cm, respectively. The band sprayer was equipped with either one or two nozzles per row of, respectively a Medium or a Fine spray quality. Spray volume for the band sprayer was 130 l/ha and 200 l/ha for resp. the maize and the sugar beet crop, defined by the difference in row width of both crops (resp. 0.75 m and 0.50 m). Crop height of the sugar beet (4–8 leaves) and of the maize (3–5 leaves) was 10–15 cm.

Drift reduction due to the use of the band sprayer was 90% compared with a field sprayer (300 l/ha, medium nozzle type). The drift reduction was achieved both with a single-nozzle and a dual-nozzle version per crop row (Van de Zande et al. 2000e).

4.1.4 Crop height

In a wheat crop the effect of crop height on drift was measured. It was found that there is no difference between the drift for 40 cm high summer wheat and 80 cm high winter wheat. For both crop heights, however, the drift was higher than for spraying on bare soil. In all cases spraying with an air-assisted sprayer resulted in a lower drift (Stallinga et al. 1999).

4.1.5 Sprayer boom height

Although not compared in the same experiments but based on the number of repetitions, it can be concluded that a decrease in sprayer boom height from 0.7 m (experiments 1992–1994) to 0.5 m (experiments 1997–1998) above a 0.5 m crop canopy reduces spray drift with 70% on the distance 2–3 m from the last nozzle when spraying a potato crop (300 l/ha). When sprayer boom height was reduced the effect of air assistance on drift reduction increased from on average 50% for the 0.7 m boom height to 70% for the 0.5 m boom height (Van de Zande et al. 2000d).

In a series of field experiments performed in 1999 the effect of lowering the sprayer boom height was quantified for sprayer boom heights of 30, 50 and 70 cm above crop canopy. Conventional spraying was compared with air-assisted spraying at the three heights above an arable crop.

At a distance of 2–3 m from the last nozzle perpendicular to the driving direction, spray drift was reduced by 54% for conventional spraying when the boom height was decreased from 70 cm to 50 cm above crop canopy. When the boom was lowered from 50 cm to 30 cm drift reduced by 56%. Lowering sprayer boom height from 70 cm to 30 cm resulted in 80% drift reduction. The use of air-assistance reduced drift on average by 86% at surface water distance, irrespective of boom height (De Jong et al. 2000a).

4.1.6 End nozzle

Overspray of plant protection products when spraying the edge of the field can be reduced by the use of an end nozzle. An end nozzle produces a cut-off spray fan like from an off-centre (OC) or UB nozzle type. Depending on the placement of the last nozzle towards the crop-edge the nozzle is placed in the last nozzle connector or 0.2 m to the outside (potatoes). An end nozzle (UB8504), in combination with a low-drift nozzle (DG11004), reduced spray drift by 20% (60% with air assistance) at 2–3 m distance from the last nozzle (Van de Zande et al. 2000d). At 1–2 m distance this effect was 50% (80% with air assistance).

4.1.7 Orchards

The reference situation for orchard spraying in The Netherlands is a cross-flow fan sprayer spraying in an orchard with leaves on the trees (LAI 1.5–2) and an average wind speed of 3 m/s. In 1991–1994 spray drift was assessed for this situation and for drift-reducing spray techniques (cross-flow orchard sprayer with reflection shields and a tunnel sprayer). For the cross-flow orchard sprayer the spray drift deposition on the soil at 4.5–5.5 m downwind of the last tree was 6.8% of the application rate per surface area.

Compared to the reference situation a tunnel sprayer achieved a reduction in spray drift on the soil surface of 85% and a cross-flow fan sprayer with reflection shields a reduction of 55% (Huijsmans et al. 1993). Spraying trees without leaves increased spray drift 2–3 times compared to spraying trees with full foliage. A windbreak on the outer-edge of the field reduced spray drift 70–90% on the zone 0–3 m downwind of the windbreak (Porskamp et al. 1994a).

4.1.8 Nursery trees

In a series of experiments (1996–1997) in high nursery (alley) trees, a conventional sprayer equipped with flat-fan nozzles was compared with a conventional axial fan sprayer with hollow cone nozzles (Porskamp et al. 1999a). The comparison was made for two tree types: spindle form and transplanted alley-trees. The level of spray drift deposition next to the sprayed field did not differ for the two nozzle types. The spray drift deposition on the soil at 3–4 m from the last tree row was, for the transplanted trees 13.6% and for the spindle trees 3.3%.

5 Spray deposition and biological efficacy

5.1 Arable crops

Through the growing season crops change considerably in their size and structure. A cereal crop for example, which may have provided little ground cover and flat spray targets early in the season, rapidly develops into a dense canopy with significant structure as it matures. The situation is somewhat different in row crops such as potatoes and beet. Row crops have been more easily identified as being three-dimensional targets and for many years growers have accepted the need to direct their sprays towards the intended target and to account for growing foliage.

5.1.1 Potatoes

In a series of field experiments (1991–1994) the effect of spray technique, dose of the agrochemical and spray interval was examined (Van de Zande et al. 2000a). The spray techniques used were a conventional spray applying 200 l/ha with Medium spray quality nozzles, and an air-assisted application using identical settings of the sprayer. Spray dose was varied between full dose, 75% and 50% of the recommended rate, including non-treated plots. Spray interval was fixed either at a weekly or a fortnight interval. Experiment setup was a complete random block-design of field plots of 7 m width and 25 m length. Spray deposit was measured in a quantitative and a qualitative way by means of a fluorescent tracer and water sensitive papers. Foliar blight infestation was evaluated on a weekly interval. Tuber blight was assessed at harvest time and after a period of storage. Air assistance (5/8 of full capacity) increased spray deposit at the total leaf area of the potatoes with 8%. The use of air assistance (Fig. 3) changed the spray deposit pattern for top, middle and bottom leaf levels. The spray penetrated crop foliage to a greater depth and more spray was deposited on the bottom side of the leaves when using air assistance. Ground deposit did not increase by the use of air assistance. Spraying at a weekly interval, late blight control was improved by using air assistance. When increasing the length of the spray interval, the level of blight control decreased, irrespective of the spray technique. Reducing spray dose also decreased late blight control both for conventional as for air-assisted spraying.

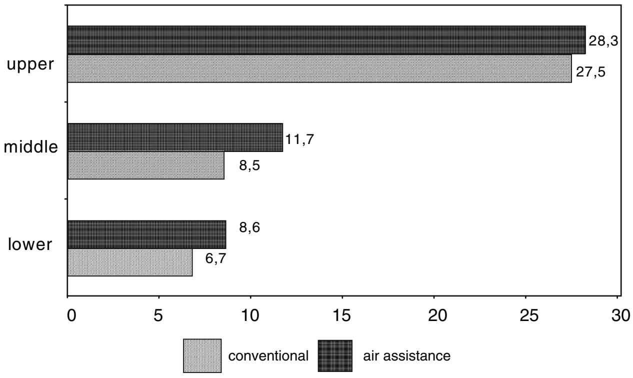

Fig. 3 Mean total spray deposition for all spraying seasons at three leaf levels in a potato crop, averaged for top and bottom leaf sides. Spraying 200 l/ha with a Medium spray quality, conventional and with air assistance application

5.1.2 Cereals

The growth stages of cereals (Zadoks et al. 1974) can be used to classify spray deposition during the growing season. The spray deposited on a cereal crop and the soil surfaces beneath are with respect to growth stage evaluated from literature (Van de Zande et al. 2000c). Spray deposition on the ground below cereals was on average 52% for the whole growing season. Spray deposition on leaf canopy in cereals was on average 67%. Increased plant deposition occurred with the use of air assistance in almost all growth stages (Fig. 4). Air assistance gives an average of 74% deposition throughout the growing season, this being 7% more than with conventional spraying.

Soil and leaf deposition in winter wheat varies throughout the period from early January when the crop is first sprayed until harvest around August. Initially, when crop structure is very open almost all the spray is deposited on the ground. As crop development begins, as is indicated with a theoretical LAI development based on the WOFOST crop growth model (Van Diepen et al. 1989), soil deposition diminishes and leaf deposition increases.

5.1.3 Orchards

Average deposition on leaves on apple trees is around 50%. This is the same for conventional (cross-flow) and tunnel

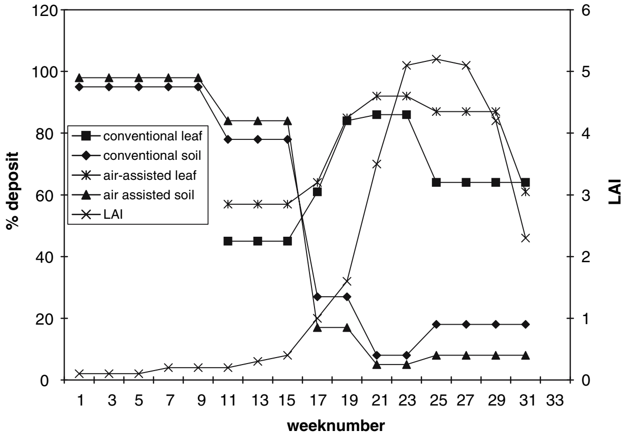

Fig. 4 Spray deposition on leaf canopy and on soil surface related to Leaf Area Index when spraying a winter wheat crop (after Van de Zande et al. 2000a, b, c, d, e)

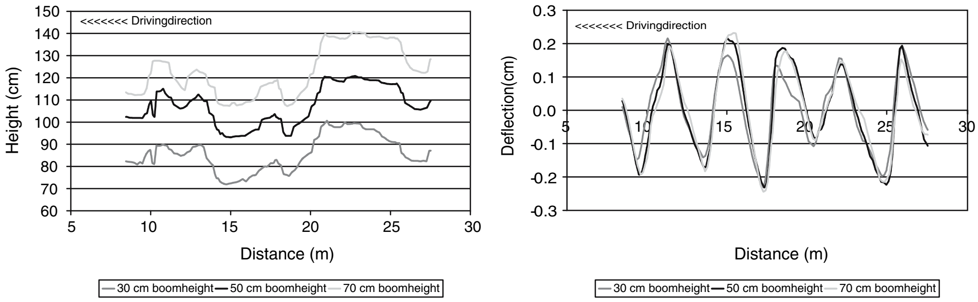

Fig. 5 Left diagram: Height and distance measurement of a sprayer boom in the field or three different heights relative to the ground. Right: Deflection in the horizontal plane of the sprayer boom, for the same three different heights

sprayers (Porskamp et al. 1994b; Heijne et al. 1993). When spraying apple trees in full leaf, spray deposition on the ground is on average 25%. Spray deposition on the soil for tunnel sprayers can be reduced by 50% compared to cross-flow sprayers. When trees are not in leaf, spray deposition on the soil is three times higher then when the trees are sprayed in full leaf.

6 Boom movements of field sprayers

For measuring boom movement in the field a laser distance measurement device together with an ultrasonic height indicator was used (de Jong et al. 2000a). These two devices together were able to measure the trajectory of the sprayer boom under field circumstances with a measuring frequency of 10 Hz creating input for the computer model DEPOFIX.

6.1 Measured boom movement and spray deposition

In the field sprayer boom movements both in the vertical and in the horizontal plane do occur simultaneously. Figure 5 shows part of a field measurement of the boom movements at the tip of a sprayer boom (de Jong et al. 2000b). When the measured 50 cm boom height and horizontal movement data (Fig. 5) were taken as input into the computer model DEPOFIX the spray deposition on a flat surface was simulated for a flat fan nozzle (Fig. 6).

The influence of vertical deflection of the boom height on deposition is difficult to retrieve when combining Figs. 5 and 6. When the horizontal deflections of Fig. 5 and the deposition of Fig. 6 are matched together, a backward deflection of the sprayer boom leads to the largest deposition (18 m and 26 m distance). A forward movement of the boom leads to lower deposition (16 m). The horizontal movements have more influence on the spray distribution than the vertical movements. An increase of the boom height smoothes the negative influence of boom movement on spray distribution.

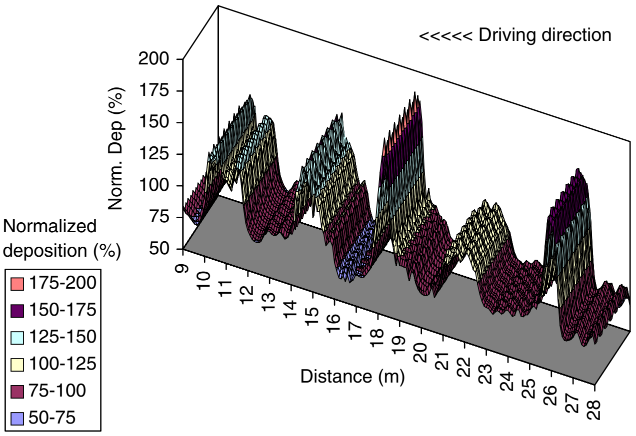

Fig. 6 Normalised deposition (%) over 19 m travelling distance for the last seven nozzles on the boom; model calculation with the movement data (vertical and horizontal) of the 50 cm boom height in a field situation as seen in Fig. 5

7 Greenhouses

An inventory was made of data on spray distribution, application quality, spray evenness, leaf coverage and soil and roof contamination in Dutch greenhouses (Van Zuydam and Van de Zande 1996) for different spray techniques. Techniques evaluated were a Low Volume Mister, a high-volume application and a low-volume application with spray-sticks, booms and masts. The condition of the average spraying equipment used in daily practice proved to be variable and not of a high standard.

A mathematical model was developed to predict the emission of crop protection products from the greenhouse during and after spraying (Van Os et al. 1993). Emission from a greenhouse depends greatly on the volatility of a pesticide and the natural air exchange of the greenhouse. From a closed greenhouse (ventilation rate half of the greenhouse volume per hour) 25–50% of the applied

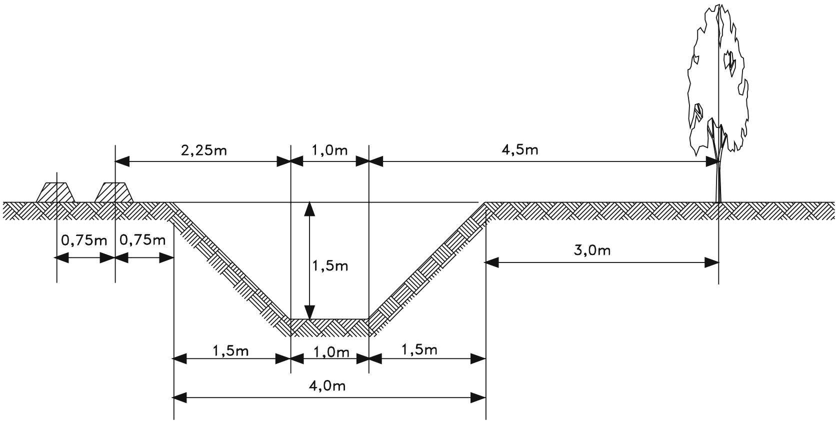

Fig. 7 Representation of the place of the ditch, embankments and water surface, and the last rows of a potato crop and a tree row in an orchard (after Huijsmans et al. 1997)

pesticide emits when applied with a LVM. In total 5–20% of the applied pesticide emits during application.

8 Discussion

Results from reported IMAG spray drift research are summarised by Huijsmans (1997) and incorporated in Dutch legislation. In the Surface Water Pollution Act and the Pesticide Act criteria for drift deposit on surface water are used depending on spraying technique and period of use during the growing season. The data used in the Pesticide Act are officially published (VROM/LNV 1998). The width of spray and crop free zones are defined for different crops in the Water Pollution Act (WVO), which has come into force from the year 2000 onwards (V&W/VROM/LNV 2000). In the WVO, packages of drift-reducing measures are described for implementation on the outer 14 m of the fields by Dutch farmers. Minimal spray- and crop-free buffer zones are described depending on the spray drift-reducing measures used. A minimum drift-reducing package for arable farming is the use of low-drift nozzles, a sprayer boom height of 0.5 m and an end nozzle, and a crop free buffer zone of 1.5 m. This buffer zone can be reduced to 1.0 m with the additional use of air assistance on the sprayer, a tunnel sprayer or planting a catch crop on the field boundary.

In order to apply a risk assessment of pesticides the results are presented on a uniform basis and expressed as percentage of the application rate per surface area, at a distance of 2.25–3.25 m (for a potato crop) or 4.5–5.5 m (for orchards) of the last crop row (Huijsmans et al. 1997), being the place where the ditches are commonly situated (Fig. 7).

The outlined spray drift reduction measures can meet the set goals by the MYCPP, 90% reduction in spray drift. However, in many cases these goals are overruled by the eco-toxicological risk values of plant protection products to be met. Going down to levels lower than 0.2% spray drift deposition in surface water is not exceptional. As a sanction of not meeting the set MYCPP goals restrictions on availability and use of agrochemicals are implemented.

Further research on spray drift is therefore needed. This holds also for the basic reason for spraying: crop protection with ensured biological efficacy. As in many cases spray drift-reducing measures are not evaluated for its biological results.

The results demonstrate that, based on spray drift research, a differentiated pesticide and water quality policy can be outlined and performed. The right choice of spray technology can be used to optimise biological efficacy, minimise spray- and crop-free buffer zones and maintain acceptable levels of eco-toxicological risk in the surface water. Spray technology plays a key role in the environmental risk assessment for pesticides.

References

van Diepen, C. A., Wolf, J., van Keulen, H., & Rappoldt, C. (1989). WOFOST: A simulation model of crop production. *Soil Use and Management, 5*(1), 16–24.

Heijne, B., van Hermon, E. A., Smelt, J. H., & Huijsmans, J. F. M. (1993). Biological evaluation of crop protection windtunnel sprayers with reduced emission to the environment in apple growing. In *Proceedings A.N.P.P.-B.C.P.C. second international symposium on pesticides application, Strasbourg, 22–24 Sept. 1993*. BCPC, Vol 1/2, pp. 321–330.

Huijsmans, J. F. M., Porskamp, H. A. J., & Heijne, B. (1993). Orchard tunnel sprayers with reduced emission to the environment. Results of deposition and emission of new types of orchard sprayers. In *Proceedings A.N.P.P.-B.C.P.C. second international symposium on pesticides application, Strasbourg, 22–24 Sept. 1993*. BCPC, Vol 1/2, pp. 297–304.

Huijsmans, J. F. M., Porskamp, H. A. J., & van de Zande, J. C. (1997). Spray drift reduction in crop protection application technology. Evaluation of spray drift in orchards, field crops and nursery tree crops spraying (state-of-the-art December 1996). In *Institute of agricultural and environmental engineering, IMAG-DLO report 97-04, Wageningen. 41p* (In Dutch with English summary).

Holterman, H. J., van de Zande, J. C., Porskamp, H. A. J., & Huijsmans, J. F. M. (1997). Modelling spray drift from boom sprayers. *Computers and Electronics in Agriculture, 19*, 1–22.

de Jong, A., Michielsen, J. M. G. P., Stallinga, H., & van de Zande, J. C. (2000a). *Effect of sprayer boom height on spray drift*. Gent: Mededelingen Univ.

de Jong, A., van de Zande, J. C., & Stallinga, H. (2000b). The effects of vertical and horizontal boom movements on the uniformity of spray distribution. In *Paper 00–PM–105 presented at AgEng 2000, Warwick, UK.* 9pp.

MYCPP (1991). Multi year crop protection plan. Tweede Kamer, Vergaderjaar 1990–1991, 21677, nrs3–4, SDU Uitgeverij,'s-Gravenhage. 298pp (In Dutch).

van Os, E. A., Holterman, H. J., & Klomp, G. (1993). Management of emission flows of pesticides from glasshouses. *Acta Horticulturae, 372*, 135–141.

Porskamp, H. A. J., Michielsen, J. M. G. P., & Huijsmans, J. F. M. (1994a). The reduction of the drift of pesticides in fruit growing by a wind-break. In *Institute of agricultural and environmental engineering, IMAG-DLO report 94-29, Wageningen.* (In Dutch with English summary) 29 pp.

Porskamp, H. A. J., Michielsen, J. M. P. G., & Huijsmans, J. F. M. (1994b). Emissiebeperkende spuittechnieken voor de fruitteelt (1992). Onderzoek depositie en emissie van gewasbeschermingsmiddelen. In *IMAG-DLO Rapport 94–19, IMAG-DLO, Wageningen*, 43 pp..

Porskamp, H. A. J., Michielsen, J. M. G. P., Huijsmans, J. F. M., & van de Zande, J. C. (1995). Emission-reducing pesticide application in potato growing. The effects of air assistance, nozzle type and spray-free zone on the drift deposition outside the field. In *Institute of agricultural and environmental engineering, IMAG-DLO report 95-19, Wageningen.* (In Dutch with English summary) 39 pp.

Porskamp, H. A. J., Michielsen, J. M. G. P., Stallinga, H., van de Zande, J. C., van den Boom, A. P. C. (1999a). Emission-reducing pesticide application in nursery-tree growing. Research on spray deposition and drift of pesticides. In *DLO Institute of agricultural and environmental engineering, report 99–01, Wageningen.* (In Dutch with summary in English) 37 pp.

Porskamp, H. A. J., van de Zande, J. C., Holterman, H. J., & Huijsmans, J. F. M. (1999b). Classification of spray nozzles based on driftability. In *Institute of agricultural and environmental engineering, IMAG-DLO report 99-02, Wageningen.* (In Dutch with English summary) 22 pp.

Southcombe, E. S. E., Miller, P. C. H., Ganzelmeier, H., van de Zande, J. C., Miralles, A., & Hewitt, A. J. (1997). The international (BCPC) spray classification system including a drift potential factor. In *Proceedings of the Brighton crop protection conference – weeds, 1997. November 1997. Brighton. UK*, pp. 371–380.

Stallinga, H., Michielsen, J. M. G. P., & van de Zande, J. C. (1999). Effect of crop height on spray drift when spraying a cereal crop. In *Instituut voor Milieu- en Agritechniek, IMAG-DLO Nota 99-71, Wageningen. 1999.* (In Dutch, not published) 23 pp.

VROM/LNV (1998). Wijziging regeling uitvoering milieutoelatingseisen bestrijdingsmiddelen. In *Ministry of VROM & Ministry of LNV, De Staatscourant 153, 14 augustus 1998*, pp. 6–7.

V&W/VROM/LNV (2000). Surface water pollution act arable farming and animal husbandry. In *Ministry of waterways and traffic, public affairs and agriculture nature management and fisheries, Staatsblad 2000 43, The Hague*. (In Dutch) 114 pp.

Zadoks, J. C., Chang, T. T., & Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Eucarpia bulletin, 7*, 42–52.

van de Zande, J. C., van Ijzendoorn, M. T., & Meier, R. (2000a). The effect of air assistance, dose and spray interval on late blight control *Phytophthora infestans* in potatoes. In *Brighton crop protection conference, 12–16 November 2000, Brighton*, pp. 1087–1092.

van de Zande, J. C., Michielsen, J. M. G. P., Stallinga, H., & de Jong, A. (2000b). Ranking of low-drift nozzles and air assistance for spray drift. In *Paper 00-PM-066 presented at AgEng 2000, Warwick, UK, 2000,* 9 pp.

van de Zande, J. C., Porskamp, H. A. J., & Holterman, H. J. (2000c). Spray deposition in crop protection. In *Environmental planning bureau series, report no. 8, Winand Staring Centre, SC-DLO, Wageningen, 2000*, 20 pp.

van de Zande, J. C., Porskamp, H. A. J., Michielsen, J. M. G. P., Holterman, H. J., & Huijsmans, J. F. M., (2000d). Classification of spray applications for driftability, to protect surface water. *Aspects of Applied Biology, 57*, 57–65.

van de Zande, J. C., Stallinga, H., & Michielsen, J. M. G. P. (2000e). Spray drift when applying herbicides in sugarbeet and maize using a band sprayer. *Mededelingen Fac.Univ. Gent, 65/2b*, 945–954.

van Zuydam, R. P., & van de Zande, J. C. (1996). Application technology, emission and safety in glasshouse spraying. *EPPO Bulletin, 26*, 95–101.