Aspects of Applied Biology 66, 2002
International Advances in Pesticide Application

Environmental risk control

By J C VAN DE ZANDE, J M G P MICHIELSEN, H STALLINGA, H A J PORSKAMP, H J HOLTERMAN and J F M HUIJSMANS

Institute of Agricultural and Environmental Engineering (IMAG), PO Box 43, 6700AA Wageningen, the Netherlands

Summary

In a newly introduced policy programme for the period 2001 to 2010 the Dutch government has formulated new goals on the reduction of chemical pesticide use and emissions to the environment. To realise these goals the development of integrated crop protection on certified farms is to be introduced to provide better guarantees for the effects of crop protection on the quality of the environment, public health (food safety) and working conditions. Within this concept the certification of crop protection application equipment needs to be fulfilled. It is suggested to develop a classification system for application techniques based on the assessment of spray deposition and biological efficacy at the target crop and spray drift losses to surface water and the air. This paper presents examples of these different types of data for potato spraying, comparing a conventional boom sprayer with an air-assisted boom sprayer.

Key words: crop protection, pesticides application, spray drift, spray deposition, classification, droplet size, air assistance

Introduction

The new crop protection policy plan of the Dutch government (LNV, 2001) for the period 2001-2010 supports the development of a sustainable agricultural production sector. In this plan food safety, public health, environment, reliability and transparency are important demands. For crop protection three objectives have been formulated in order to realise the goal of sustainable crop production: a further reduction of chemical pesticide use, a further reduction of emissions to the environment, and improving the compliance with current pesticide regulations to protect public health, the environment and workers. To realise these three objectives the Government proposes the introduction and further development of integrated crop protection on certified farms. The certification of farms provides better guarantees for the effects of crop protection and makes farming practices visible as it shows how growers meet the demands for sustainable crop production. This is important as consumers are making increasingly greater demands on reliable information and transparency of production processes. The objective is to reduce the environmental burden by 90%, through a 95% reduction in the use of chemical pesticides by 2010 compared with 1998. The new crop protection policy will be evaluated in 2004. If by that time the number of certified farms is less than 90% of all farms, legal measures will be taken. These measures can be that chemical pesticide usage is only permitted on those certified farms. Within this concept the certification of crop protection application equipment is needed.

Tools for the classification of pesticide application equipment are not general available. On the other hand methods have been developed for nozzle classification based on measurement of spray quality (Doble *et al*., 1985; ASAE, 1999) and driftability (Southcombe *et al*., 1997). Porskamp *et al*., (1999) described a nozzle classification system for driftability based on Phase

Doppler Anemometry and a drift model (Holterman *et al*., 1997). The classification of nozzles for driftability can also be determined from comparative measurements in a windtunnel (Walklate *et al.*, 2000; Herbst *et al.*, 2000). For full operational systems (sprayers) predominantly field tests are required to quantify spray deposit, spray drift (both as soil deposit and as airborne). Classification of sprayers towards driftability has recently been implemented in different countries, especially in relation to water pollution control. Germany (BBA, 2000a, 2000b), the UK (Gilbert, 2000) and the Netherlands (V&W *et al*., 2000; V&W/LNV, 2001) classify spray drift deposition (risk to surface water) in one or more classes of drift reduction. Test methods for spray drift and evaluation distances, however, vary between research institutes but are subject to standardisation (ISO 22866 & ISO 2001). Environmental risk is more than spray drift alone. Classification methods, solely towards spray deposition on the soil surface next to the field, have neglected other important effects of airborne drift. Drift reducing measures can also influence crop deposition and effect biological efficacy, or increase soil deposition underneath crop canopy and therefore increases the risk of water pollution by the soil leaching mechanism.

In this paper an evaluation is made of potato spraying by comparing a conventional sprayer with an air-assisted sprayer using different nozzle types and spray volumes. In particular the evaluation focuses on spray deposition in crop canopy, soil deposition underneath the canopy, spray drift deposition on the soil next to the field and airborne drift next to the field.

Material and methods

Field trials have been performed to assess the spray deposition in potatoes (Zande et al., 1995, 1999, 2000a) and the spray drift next to a field (Porskamp *et al.,* 1995; Michielsen *et al*., 1999; Stallinga *et al.,* 2000; Jong *et al*., 2000; Zande *et al*., 2000b, 2000c).

Spray deposition

At different times during the growing season spray deposition measurements were carried out by adding the fluorescent dye (Brilliant Sulfo Flavine BSF) to the spray liquid at a concentration of 0.5 g litres^{-1}). The non-ionic surfactant (Agral N) was added at a concentration of 1 g litres^{-1} to mimic a pesticide formulation. After spraying the target crop, the dye was extracted from spray collectors made from chromatography paper strips (20 cm long x 2 cm wide), which were folded around and attached to the leaves with paper clips. The collectors were placed systematically at three leaf heights (top, middle and bottom), four collectors at each height. Collectors, 100 x 8 cm filter tissues, were placed on the soil surface on and between the ridges to examine exposure of the soil surface. Above the crop canopy a collector tissue was placed to measure total spray deposition (spray dose). For each measurement a single pass was made across the trials. Measurements were carried out at three places across the sprayer boom and tests we repeated at three different growth stages during the growing season.

Drift measurements

Drift measurement were carried out according to the ISO-draft standard (ISOCD 22866; ISO/TC23/SC6 dated 01-09-2001) adapted for the situation in the Netherlands to evaluate the contamination of the ground, ditch and surface water next to the target crop. Drift was measured on bare soil surface at the downwind edge of a field planted with potatoes. The swath-width of potatoes sprayed was 18m. The length of the sprayed track was, at least, 50m. The distance of the last downwind nozzle to the edge of the field (the last crop leaves) was determined.

Spray drift measurements were carried out by adding fluorescent dye Brilliant Sulfo Flavine (BSF; 2.5 g litres^{-1}) and non-ionic surfactant (Agral; 0.1%) to the spray liquid. Ground deposit was measured on horizontal collection surfaces placed at ground level in a double row downwind of the sprayed swath. 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 made of synthetic cloth (Camfil CM360) with dimensions of 0.50x0.08m and 1.00x0.08m.

Airborne spray drift was measured at a distance of 5.5 m from the last downwind nozzle. The collection of airborne spray was made using two separate lines with attached collectors at 0, 1, 2, 3, and 4 m height. Collectors used were spherical synthetic cleaning pads (Siral Siebauer 00140; diameter 0.08 m). After exposure the collectors were washed and the BSF concentrations of the washings measured by fluorimetry (Perkin Elmer fluorimeter, LS-2B; LS-30). The measured deposits were expressed as percentage of the application rate of the sprayer (spray dose). After log-transformation the results of the deposition measurements were statistically evaluated using Genstat statistical software (Payne, 1993). Statistical analysis of the data was done using analysis of variance (ANOVA 5% probability).

Meteorological conditions during spray drift measurements were recorded. Wind speed and temperature were recorded at 5 s interval at 0.5 and 2.0 m height, using cup anemometers and Pt100 sensors, respectively. Relative humidity was measured at 0.5 m height and wind direction at 2.0 m height.

Results

Spray deposition

Zande *et al*. (2000a) assessed spray deposition at different heights in the potato crop for conventional spraying and with the additional use of air assistance (Fig. 1). The deposit of spray liquid on the upper part of the plant canopy was significantly higher than on the middle and lower leaf level (Table 1). In general, deposit on the topside of leaves was higher than on bottom side of leaves. With the additional use of air-assistance on the field sprayer, deposition on the middle and lower leaf levels was higher for both the top and bottom side of the leaves compared to conventional application. With air-assistance, deposition on the bottom side of middle and lower leaf levels was higher than with conventional application. Deposition on the lowest leaf level for air-assisted spraying was as high as it is on the middle leaf level for the conventional spraying.

Table 1. *Mean spray deposition (% of sprayed volume) for all seasons spraying recorded at three leaf levels in a potato plant canopy differentiated to top and bottom side of the leaf tissue, spraying 200 l/ha with a Medium spray quality conventional application and with additional use of air assistance on the field sprayer (after Zande et al., 2000a)*

air assistance	leaf surface	leaf level		
		upper	middle	lower
no	Top	33.8	10.2	6.6
	Bottom	6.2	1.6	1.4
5/8 of full	Top	33.9	10.8	8.4
	Bottom	8.4	2.8	2.2

The total spray volume deposit on the crop was computed by multiplying the deposit, expressed as a volume flux, by the estimated leaf surface areas at the appropriate heights. Typical mean leaf surface area measurements were 2.3 m^2 per m^2 of soil surface (i.e. Leaf Area Index = 2.3). The total deposit on plant leaf tissue (Fig. 1), was significantly higher for the 200 litres ha^{-1} spray application when air-assistance was used (air-assisted 48.6%; conventional 42.7%). With air-assistance, the deposit on the middle and lower leaf level was significant higher than for conventional spraying without air-assistance.

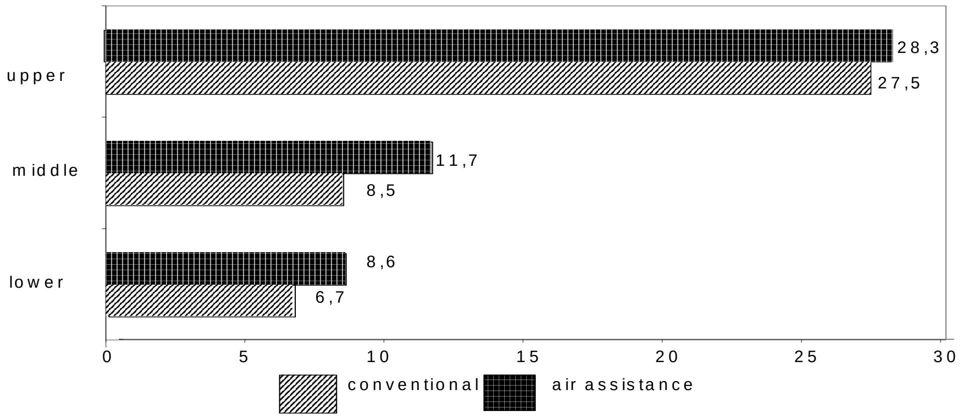

Fig. 1. Mean total spray deposition (% of sprayed volume) at three leaf levels in a potato crop. Spraying 200 l/ha with a Medium spray quality and a conventional or an air-assisted application (after Zande *et al.*, 2000a)

Spray deposition measurements are representative for a specific period during the growing season. In general three distinct stages in crop growth can be distinguished during the growing season of potatoes:

- *A* where the leaf canopy is in distinct rows
- *B* where the leaf canopy covers soil surface completely
- *C* where the leaf canopy is decreasing because of ageing

During each of these periods there are changes in coverage of the soil by the crop. From the example above and other studies it follows that this affects spray deposition both on the leaf canopy and on the soil beneath the crop (Zande *et al*., 2002). This is shown in Fig. 3 and 4 for conventional hydraulic spraying and air-assisted spraying.
At growth stage *A* LAI is between 1 and 2 and soil coverage is 20-50%. Deposition in the crop canopy at growth stage A is on average 46% (Table 2). At growth stage *B***,** where soil coverage is complete and the crop is growing vigorously, LAI rises to 5.1. Average deposition of spray in the crop canopy at this stage B is 68%. Later in the growing season, when plant stems lie between the ridges (stage *C*) LAI reduces again to 1-2. Deposition on the potato plant also reduces and, for conventional spraying, it is around 56%.

Table 2. *Spray deposition (% of sprayed volume) on potato plant for different growth stages and spray techniques.*

	Growth stage	A	AB	B	C	Avg. all season
Spray technique	Volume (litres/ha)					
Conventional	avg. 100-300	46	60	68	56	57
Air assistance	avg. 100-300	40	60	72	46	54

Using air-assistance on field sprayers changes the deposition pattern within the potato crop canopy. Penetration of the spray into the canopy is increased and by using air assistance more spray is deposited at the middle and lower levels (Fig. 1). At early and late growth stages (*A* and *C*) deposition in the crop using air assistance is about 6-10% lower than with conventional techniques. With a fully mature canopy (*B*) the use of air assistance increases spray deposition in the crop by an average of 4%. Improvements in deposition with air-assistance are especially good with fine sprays and low volumes (100 litres ha^{-1}). The effect of spray volume is presented in Fig. 3.

Biological effects

Zande *et al.* (2000a) concluded that late blight *Phytophthora infestans* infestation was lower with air assisted spraying than with conventional spraying. At full dose rate and a weekly spray interval this difference was significant (table 3).

Table 3. *Leaf late blight (Phytophthora infestans) infection in potatoes, presented as Area under Disease Progressive Curve (ADPC) and tuber infection (%). Effect of spray interval, dose and spray technique (conventional or air assistance) for the period 1992-1994 and individual years (after Zande et al., 2000a)*

Spray interval	%	method	ADPC			
(days)	dose		mean	1992	1993	1994
7	100	C	118	323	28	4
7	100	A	89	259	6	1
7	75	C	167	431	65	5
7	75	A	154	412	45	3
7	50	C	310	854	63	11
7	50	A	277	775	51	5

Other experiments (Zande *et al*, 1999) concluded that at the time of first infection, the level of infection in the air-assisted plots was significant lower. At the end of the growing season, after repeatedly spraying, no difference could be found. However, on individual recording dates the effect of air-assistance on leaf late blight control was significant.

It was concluded that in general the relation between spray deposition and leaf and tuber infection and dosage is not clear. Combining spray quantity and quality analysis (coverage, number of spots) can lead to more insight and a better explanation of the biological effects.

Environmental risk

Spray deposition on the soil underneath crop canopy

The effect of air-assistance on soil exposure underneath the crop canopy was significant (Zande *et al.*, 1999) and shown in Fig. 2. Deposition on the soil surface on top of the potato-ridges and between them was significant higher for air-assisted spraying at both volumes of 150 litres ha^{-1} and 300 litres ha^{-1}. Spray deposition on the soil surface underneath the potato crop did not differ between both volumes. Deposition on top of the potato-ridges was higher than between ridges.

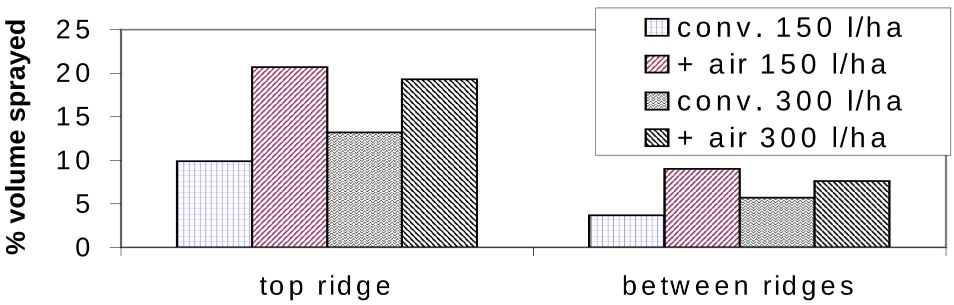

Fig. 2. Exposure of the soil surface (% of sprayed volume) underneath a potato after spraying 150 litres ha^{-1} or 300 litres ha^{-1}, conventional and with air assistance (Zande *et al.*, 1999)

Zande *et al.* (2000a) found no significant effect of air-assistance on soil exposure. Deposition on the soil surface underneath the potato crop was 24% of the applied volume both for conventional and air-assisted spraying. Deposition on top of the potato-ridges was higher than between ridges. During the growing season of the potatoes as leaf coverage changes and spray deposit on the crop varies accordingly (Table 2) a change in deposition on the ground also occurs (Zande *et al.*, 2002). In Table 4 spray deposit is presented for the soil surface underneath the potato crop. At growth stage *A* deposition on the soil surface between the potato rows is at full dose (100%). Averaged with the deposit underneath the plant rows on top of the ridges deposition of the spray is still 39%. On a completely covered soil surface in stage B spray deposition on the ground decreases to 7%.

Table 4. *Spray deposit (% of sprayed volume) on the soil surface underneath a potato plant at different growth stages and for different spraying techniques.*

Spray technique	Growth stage Volume (l/ha)	A	AB	B	C	Avg. all season
Conventional	avg. 100-300	39	17	7	23	22
Air assistance	avg.100-300	50	21	10	27	27

At growth stage C the average soil deposition is 23%. The use of air assistance increases spray deposit on the soil surface in all growth stages (Fig. 4), resulting in an all-season average increase in soil deposition from 22 to 27%.

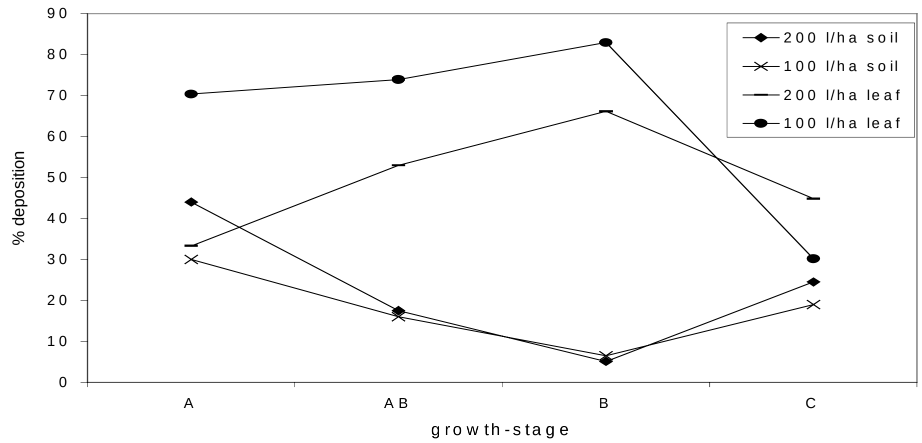

Fig. 3. Total spray deposit (% of sprayed volume) on the potato plants and soil surface underneath plant at different growth stages: effects of spray volumes (after Zande *et al.*, 2002).

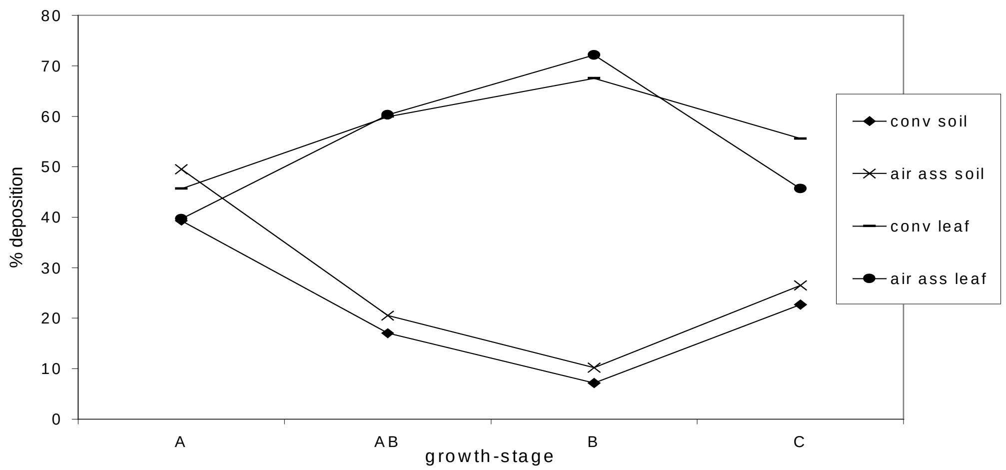

Fig. 4. Total spray deposit (% of sprayed volume) on the potato plants and the ground underneath plants at different growth stages: effects of air assistance (after Zande *et al.*, 2002)

It is expected that at the start of the season more spray will be deposited on the soil surface than on the crop. Since most of the spray deposits on the crop when the maximum LAI occurs and this diminishes towards the end of the season, we can expect that deposition on the soil will show the inverse of this (Zande *et al.*, 1998).

Spray drift next to the field - Spray drift deposit

The results of the spray drift measurements (Michielsen *et al*, 1999; Zande *et al.*, 2000b) for different nozzle types and a 300 litres ha^{-1} spray volume (ISO 04) are presented in Fig. 5.

Sprayer I and Sprayer II, resp. a similar mounted and trailed sprayer type and equipped with the same reference nozzle (XR11004), resulted in a different level of spray drift deposition. Therefore the nozzle types are compared with the reference nozzle on the same sprayer. The statistical analysis of spray drift deposition on 2-3m distance from the last nozzle is presented in Table 5.

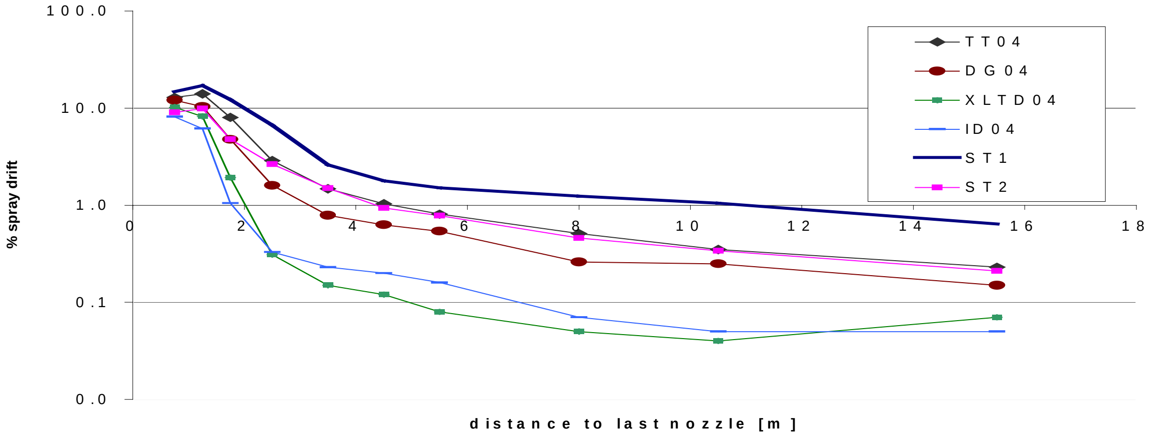

Fig. 5. Spray drift deposit (% of sprayed volume) at different distances from the last nozzle for different low-drift nozzle types (ISO 04 @ 300 kPa) when spraying potatoes with a spray volume of 300 litres ha^{-1}. Standard nozzle type is XR11004 on a mounted (ST1) and a trailed sprayer (ST2) (after Zande *et al.*, 2000b).

Table 5. *Average spray drift deposition (% of sprayed volume) for 04 nozzle types (@ 300 kPa) spraying 300 litres ha^{-1}, on 2-3m distance from the last nozzle*

sprayer	air assistance	ST	DG	TT	ID	XLTD
I	-	6.68[a]	1.60[c]	2.89[b]		
	+	1.22[a]	0.73[b]	0.64[b]		
II	-	2.64[a]			0.33[b]	0.31[b]
	+	0.51[a]			0.09[b]	0.09[b]

[a], [b], [c] statistical significant differences (α<0.05) are indicated with different letters in the same row

The difference in spray drift deposition between the conventional and the air assisted spraying is for each nozzle type significantly different (α<0.05). The values for both Sprayers I and II for the Standard nozzle type (resp. 6.68% and 2.64%) are significantly different, also for the air-assisted spraying (1.22% and 0.51% resp.). It is suggested that these differences in spray drift deposit levels were caused by sprayer boom height setting. The accurate measurement of boom-height above a crop canopy is troublesome. Moreover there can be a difference in stationary measured and dynamic boom height when driving with a mounted (ST1) and a trailed sprayer (ST2). Spray drift deposit from the low drift nozzles is significantly different to the deposit from the standard nozzle, with both conventional and air assistance sprayers.

The different nozzles can be ranked according to the relative spray drift deposit (Fig. 6,7) compared to the standard (set to 100). Groups of nozzles either with or without air assistance can easily be classified for spray drift reduction. For the 300 litres ha^{-1} spray volume (Fig. 6) the nozzles TT11004 and DG11004 reduce drift deposit 50-75%. The combinations standard+air, ID12004, DG11004+air, XLTD11004 and TT11004+air reduce drift by 75-90%, and the combinations ID12004+air and XLTD11004+air reduce drift deposit by more than 95% at 2-3m from the last nozzle.

Additional drift measurements (Stallinga *et al.*, 2000) were done for the 150 litres ha^{-1} nozzles (ISO 02). For these nozzles the ranking for spray drift reduction classes (Fig. 7) was: XR11002+air 0-25%, DG11002+air and XLTD11002 in class 50-75% reduction, TT11002+air, XLTD11002+air, standard XR11004+air, ID12002, and the combination ID12002+air in the class 75-90% drift reduction. The DG11002, TT11002 and XR11002 nozzles produced resp. 29%, 145% and 185% more spray drift compared to the reference nozzle (XR11004).

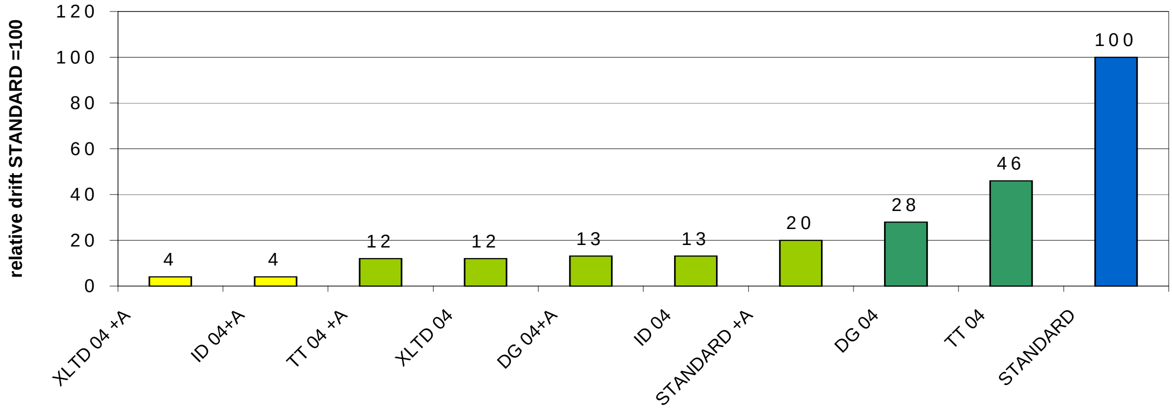

Fig. 6. Relative spray drift deposit at 2-3m from the last nozzle for different low-drift nozzles (ISO 04 @ 300 kPa) and air assistance (+A) when spraying potatoes with a spray volume of 300 litres ha^{-1}. Standard nozzle type is XR11004 (=100).

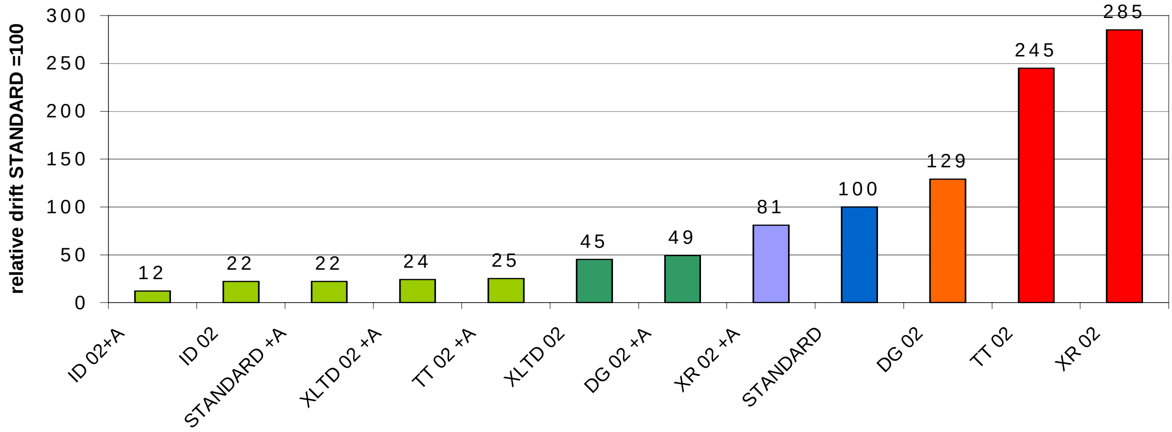

Fig. 7. Relative spray drift deposit at 2-3m from the last nozzle for different low-drift nozzles (ISO 02 @ 300 kPa) and air assistance (+A) when spraying potatoes with a spray volume of 150 litres ha^{-1}. Standard nozzle type is XR11004 (=100).

Spray drift next to the field - airborne

Similar to the spray drift deposit data the results of airborne drift at 5.5m distance from the nozzle can be presented (Table 6), averaged for the collectors upto 4m height (Michielsen *et al.*, 1999). The difference in airborne spray drift between the conventional and the air assisted spraying is for each nozzle type significantly different ($\alpha<0.05$). Airborne spray drift of the low drift nozzles is significantly different from the standard nozzle, both conventionally sprayed and

Table 6. *Average (4 m height) airborne spray drift (% of sprayed volume) for 04 nozzle types (@ 300 kPa) spraying 300 litres ha^{-1}, at 5.5m distance from the last nozzle*

sprayer	air assistance	ST	DG	TT	ID	XLTD
I	-	2.82^a	1.32^c	1.84^b		
	+	0.34^a	0.09^b	0.24^a		
II	-	2.02^a			0.42^b	0.27^c
	+	0.12^a			0.11^a	0.12^a

^{a}, ^{b}, ^{c} statistical significant differences ($\alpha<0.05$) are indicated with different letters in the same row

with the use of air assistance (except for the ID and XLTD). For a better interpretation of the reduction these airborne spray drift data can be ranked accordingly. The average drift deposition of the standard sprayer is again set to 100, and other average airborne drift values are expressed as a fraction of the reference. The different nozzle combinations are ranked according to the relative airborne spray drift deposition (Fig 8,9) compared to the standard (set to 100). For the 300 litres ha^{-1} spray volume (Fig. 8) the nozzle TT11004 reduces airborne drift 25-50%. The nozzle DG11004 reduces 50-75%, the nozzles XLTD11004 and ID12004 reduce 75-90%, the combinations standard+air, TT11004+air, ID12004+air and XLTD11004+air reduce 75-90%, and the combinations DG11004+air reduces airborne drift on 5.5m from the last nozzle more than 95%.

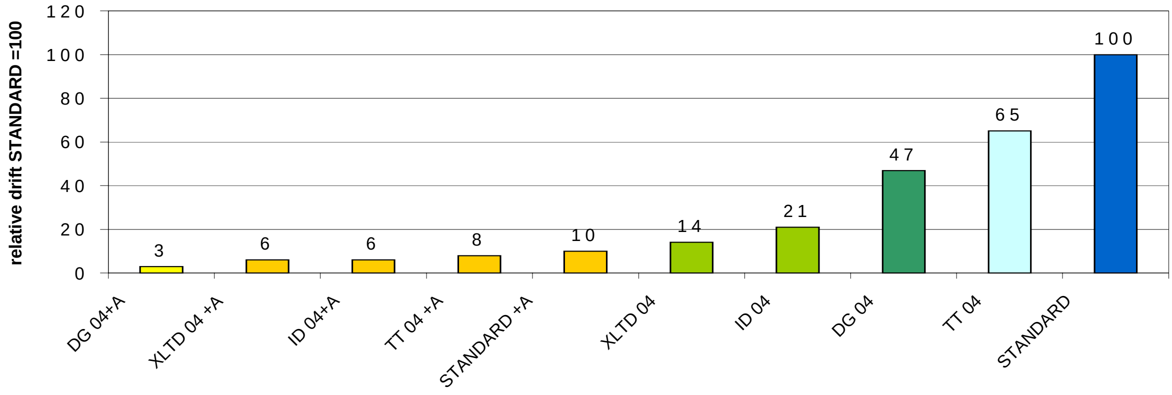

Fig. 8. Relative airborne spray drift on 5.5m from the last nozzle (averaged for 4m height) for different low-drift nozzles (ISO 04 @ 300 kPa) and air assistance (+A) when spraying potatoes with a spray volume of 300 litres ha^{-1}. Standard nozzle type is XR11004 (=100).

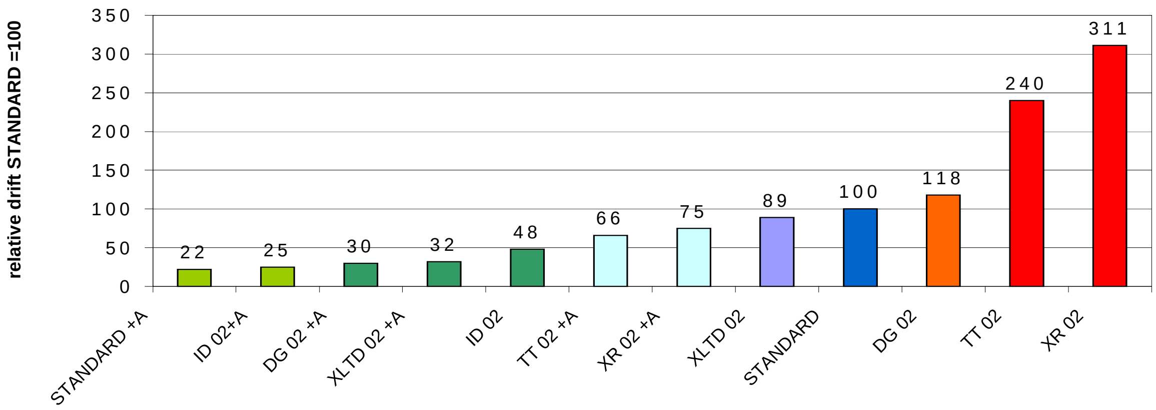

Fig. 9. Relative airborne spray drift on 5.5m from the last nozzle (averaged for 4m height) for different low-drift nozzles (ISO 02 @ 300 kPa) and air assistance (+A) when spraying potatoes with a spray volume of 150 litres ha^{-1}. Standard nozzle type is XR11004 (=100).

For the 150 litres ha^{-1} nozzles (ISO 02) the ranking for airborne spray drift reduction classes (Fig. 9) was: XLTD11002 0-25%, XR11002+air and TT11002+air in class 25-50%, ID12002, XLTD11002+air and DG11002+air in class 50-75% reduction, ID12002+air and standard XR11004+air in the class 75-90% drift reduction. The DG11002, TT11002 and XR11002 nozzles produced resp. 18%, 140% and 211% more airborne spray drift compared to the reference nozzle (XR11004).

Discussion

Spray deposition and drift is influenced by many factors. These factors can originate from the outdoors environment and meteorological conditions, the spray technique and the crop and its canopy structure. Although most measurements are performed with a standard solution of a non-ionic surfactant to mimicking a pesticide, it is known that formulation and additives can influence spray retention and drift. Therefore, these effects can change the various classifications presented here.

The presented data give additional information to establish a more generic evaluation of spray techniques towards environmental risk. Already developed systems can be updated or expanded (Parkin *et al*, 1994; Spugnoli & Vieri, 1994). Depending on the main goal (i.e. good crop protection and minimal environmental burden) one can choose an optimal spray technique. To classify accordingly it is essential to define a reference for comparison. The reference we've chosen is a conventional boom sprayer applying a 'Medium' quality spray at 300 litres ha^{-1} to a potato crop with the boom height set at 0.50m above the top of the crop canopy. It is known that crop type and canopy structure influences spray deposition (Zande *et al.*, 2002) and spray drift (Zande *et al.*, 2000c). We found differences in spray drift between a flower bulb crop, cereals, potatoes and bare soil surface (Fig. 10). Ganzelmeier *et al* 1995, Arvidsson (1997) and SDTF (1997) presented drift curves on short cut grass or cereal stubble. Fig. 10 shows that these curves can differ by, as much as, a factor of ten. Differences in the absolute levels of spray drift can also be attributed to different weather conditions during the measurements (wind speed and wind direction), the sprayer swath width, nozzle type, sprayer boom height and its movements.

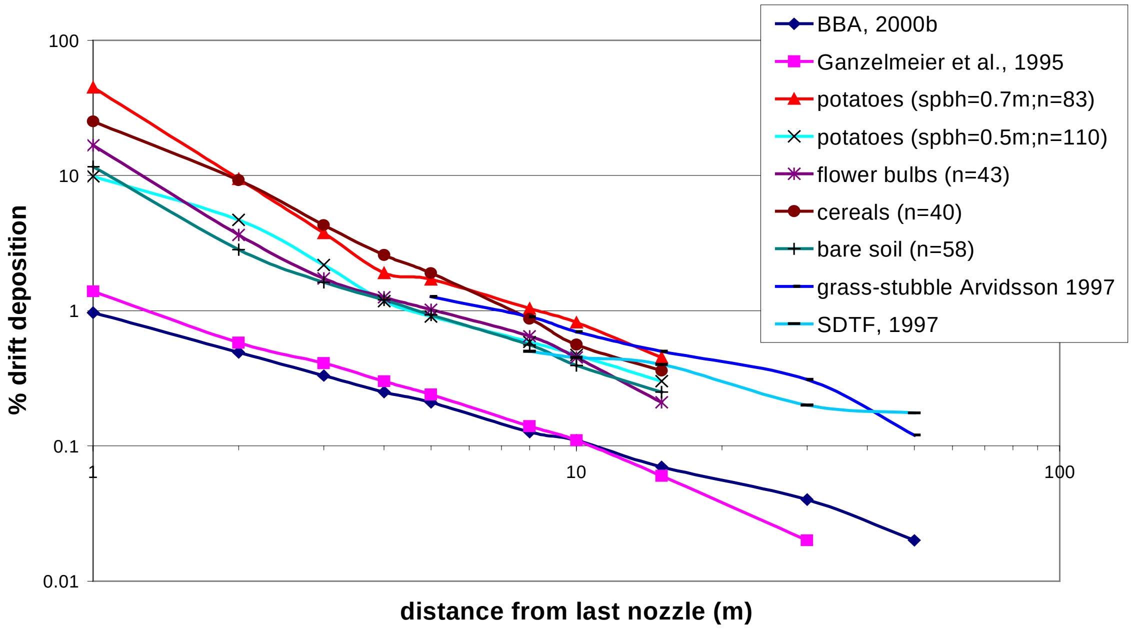

Fig. 10. Effect of crop type and environmental circumstances on spray drift (50-percentiles based on measured data), originating from different sources

Classification based on threshold levels of spray drift deposit on surface water, necessary for the authorisation of crop protection products, should be made depending on the availability of spray drift data for different regional situations (crop types, canopy structure, meteorological circumstances) with reference sprayers. It is therefore suggested that classification systems for different sprayers make relative comparisons taking into account the influence of these regional differences (ISO, 2001).

It can be concluded that spray techniques can be evaluated and ranked according to spray deposit, ground deposit due to spray drift and airborne drift. A reduction in ground deposit due to spray drift is not necessarily the same as a reduction in airborne drift. A drift reducing technique can also lead to an increased soil deposition underneath crop canopy and therefore increase the risk water contamination due to leaching for soil. Therefore to control environmental risk it is necessary to quantify all these aspects.

References

Arvidsson, T, 1997. Spray drift as influenced by meteorological and technical factors. A methodological study. Swedish University of Agricultural Sciences, Acta Universitatis Agriculturae Sueciae, Agraria 71. 1997. 144pp.

ASAE, 1999. Spray nozzle classification by droplet spectra. American Society of Agricultural Engineers, ASAE S572 AUG99, St. Joseph, 1999. 3p.

BBA, 2000a. Sechste Bekanntmachung über die Eintragung in das Verzeichnis "Verlustmindernde Geräte", Biologische Bundesanstalt für Forst- und Landwirtschaft , Braunschweig. 2000. 3p.

BBA, 2000b. Verfahren zur Eintragung von Pflanzenschutzgeräten in de Abschnitt "Abtrift" des Verzeichnisses "Verlustmindernde Geräte", Biologische Bundesanstalt für Forst- und Landwirtschaft , Braunschweig. 2000. 9p.

Doble, SJ, Mathews GA, Rutherford I & Southcombe ESE, 1985. A system for classifying nozzles and other atomizers into categories of spray quality. Proc. British Crop Protection Conference - Weeds,. pp. 1125-1133.

Ganzelmeier, H, Rautmann D, Spangenberg R, Streloke M, Hermann M, Wenzelburger HJ & Walter HF, 1995. Untersuchungen zur Abtrift von Pflanzenschutzmitteln. Ergebnisse eines bundesweiten Versuchsprogrammes. Mitteilungen aus der Biologische Bundesanstalt für Land- und Forstwirtschaft, Heft 304, Berlin. 1995. 111p.

Ganzelmeier, H & Rautmann D, 2000. Drift, drift reducing sprayers and sprayer testing. Aspects of Applied Biology 57, Pesticide application, 2000. 1-10

Gilbert, AJ, 2000. Local Environmental Risk Assessment for Pesticides (LERAP) in the UK. Aspects of Applied Biology 57, Pesticide Application, 2000. 83-90

Herbst, A & Ganzelmeier H, 2000. Classification of sprayers according to drift risk – a German approach. Aspects of Applied Biology 57, Pesticide Application, 2000. 35-40

Huijsmans, JFM, Porskamp HAJ & Zande JC van de, 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). Institute of Agricultural and Environmental Engineering, IMAG-DLO Report 97-04, Wageningen. 41p. (in Dutch with English summary)

Holterman, HJ, Zande JC van de, Porskamp HAJ & Huijsmans JFM, 1997. Modelling spray drift from boom sprayers. *Computers and Electronics in Agriculture* 19(1997):1-22

ISO, 2001. Draft standards on spray drift measuring protocol and spray drift classification. International Standardisation Organisation, TC23/SC6/WG4&WG7.

ISO 10625, 1996. Equipment for crop protection –Sprayer nozzles – Colour coding for identification. International Standardisation Organisation, Geneva.

Jong, A de, Michielsen JMGP, Stallinga H & Zande JC van de, 2000a. Effect of sprayer boom height on spray drift. Mededelingen Univ. Gent. 65/2b(2000): 919-930

LNV, 2001. *Integrated management, the way ahaed. Crop protection policy up to 2010*. Ministry of Agriculture, Nature Management and Fisheries, The Hague. 2001. 39pp.(in Dutch)

Michielsen, JMGP, Stallinga H & Zande JC van de, 1999. Spray drift reduction when using different nozzle-type, an end-nozzle and air assistance when spraying potatoes. I. Field experiments 1998, spray volume 300 l/ha. IMAG-DLO Nota P99-111, Instituut voor Milieu- en Agritechniek, Wageningen. 1999. 31pp. (in Dutch, not published)

Parkin, CS, Gilbert, AJ, Southcombe ESE & Marshall CJ, 1994. British Crop Protection Council scheme for classification of pesticide application equipment by hazard. Crop Protection 13(1994)3: 281-285

Payne, RW, 1993. *Genstat 5 Release 3 Reference Manual*. Oxford: Oxford University Press Harpenden, UK. 796pp.

Porskamp, HAJ, Michielsen JMGP, Huijsmans JFM & Zande JC van de, 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. Institute of Agricultural and Environmental Engineering, IMAG-DLO Report 95-19, Wageningen. 39p. (in Dutch with English summary)

Porskamp, HAJ, Zande JC van de, Holterman HJ & Huijsmans JFM, 1999b. Classification of spray nozzles based on driftability. Institute of Agricultural and Environmental

Engineering, IMAG-DLO Report 99-02, Wageningen. 22pp. (in Dutch with English summary)

SDTF, 1997. A summary of ground application studies. Spray Drift Task Force, Steward Ag.Res.Service, Macon. 1997. 5pp.

Southcombe, ESE, Miller PCH, Ganzelmeier H, Zande JC van de, Miralles A & Hewitt AJ, 1997. The international (BCPC) spray classification system including a drift potential factor. Proceedings of the Brighton Crop Protection Conference - Weeds, 1997. November 1997. Brighton. UK. p.371-380

Spugnoli, P & Vieri M, 1994. Classification of sprayers by hazard using multicriterion analysis. Paper 94-F-011 prsented at International Conference on Agricultural Engineering, Milano, 29th August - 1st September 1994. 8p.

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

Stallinga, H, Michielsen JMGP & Zande JC van de, 2000. Spray drift reduction when using different nozzle-type and air assistance when spraying potatoes. II. Field experiments 1999, spray volume 150 l/ha. IMAG Nota P2000-87, Instituut voor Milieu- en Agritechniek, Wageningen. 26pp. (in Dutch, not published)

V&W/VROM/LNV, 2000. *Surface water pollution act arable farming and animal husbandry*. Ministry of Waterways and traffic, Public affairs, Agriculture Nature Management and Fisheries, Staatsblad 2000 43, The Hague. 114p. (in Dutch)

V&W/LNV, 2001. *Test method low drift nozzles water pollution act arable farming and animal husbandry.* Ministry of Waterways and Traffic, Ministry of Agriculture Nature Management and Fisheries, Staatscourant 2001- 43, The Hague. P.18-21 (in Dutch)

Walklate, PJ, Miller PCH & Gilbert AJ, 2000. Drift classification of boom sprayers based on single nozzle measurements in a wind tunnel. Aspects of Applied Biology 57, Pesticide Application, 2000. 49-56

Zande, JC van de, Porskamp HAJ & Huijsmans JFM, 1994. Air-assisted spraying in potatoes -Results of deposition measurements and a biological evaluation. International Conference on Agricultural Engineering, Milano, 29th August - 1st September 1994, p. 720-721

Zande, JC van de, Porskamp HAJ & Holterman HJ, 1998. Spray deposition in crop protection. Environmental Planning Bureau Series 5, DLO Winand Staring Centre, Wageningen. 1998

Zande, JC van de, Porskamp HAJ, Michielsen JMGP, IJzendoorn MT van & Meier R, 1999. Spray deposition and biological efficacy in potatoes. In: J. Pabis & R.S. Rowinski, 1999. Papers presented at the Techniques for Plant Protection Conference, TPP, International Conference Warsaw – Poland, 23-26.05.1999. Warsaw Agriculture University, Warsaw. pp.117-125

Zande, JC van de, IJzendoorn M van, Meier R, 2000a. The effect of air assistance, dose and spray interval on late blight control *Phytophthora infestans* in potatoes. BCPC Conference - Pest & Disease 2000, Brighton 13-16 November 2000, British Crop Protection Council, Farnham. 2000

Zande, JC van de, Michielsen JMGP, Stallinga H & Jong A de, 2000b. Ranking of low-drift nozzles and air assistance for spray drift. Paper 00-PM-066 presented at AgEng 2000, Warwick, UK. 2000. 9pp.

Zande, JC van de, Porskamp HAJ, Michielsen JMGP, Holterman HJ & Huijsmans JFM, 2000c. Classification of spray applications for driftability, to protect surface water. Aspects of Applied Biology 57(2000): 57-65

Zande, JC van de, Parkin CS, Gilbert AJ, 2002. Application techniques. Chapter 3 In: MF Wilson,Optimising Pesticide Use, Wiley & Sons (forthcoming)