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A study conducted within the framework of the Sino-Dutch Pesticide Environmental Risk Assessment Project PERAP

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Summary

Drift from the application of crop protection products can cause damage to neighbouring crops, ecosystems, and human health. In this report, estimations of spray drift with reference to Chinese agricultural systems are provided, based on data from literature and a modelling study. As knapsack sprayers make up the most important tool for pesticide applications in China, this study focussed on drift from knapsack sprayers. The results presented in this report will be used to model pesticide drift and conduct an environmental risk assessment of pesticides in Chinese agricultural systems, as part of the Sino-Dutch Pesticide Environmental Risk Assessment Project PERAP.

An introduction to the different types of pesticide drift and the aims and broader framework of this study are provided in Chapter 2.

In Chapter 3, factors that have an impact on drift are discussed. These factors include:
1. Weather conditions
2. Application
3. Formulation
4. Operator care, attitude and skill
5. Composition and state of the vegetation in the field and in field margins

Moreover, the different types of nozzles that are used for spraying are assessed for their drift potential. Furthermore, a brief overview is given of measures that can be taken to reduce pesticide drift.

In Chapter 4, results from the IDEFICS spray drift model, simulating drift ground deposits and airborne spray under different climatological and crop conditions, are compared with field data on drift from knapsack sprayers from the Philippines and the Netherlands. As the literature study did not retrieve relevant drift data from China, the presented drift values could not be compared with field observations from China. The differences in observed or simulated spray drift between studies, as well as the validity of the data for Chinese conditions, are discussed.

1. Background

Drift can be defined as spray which unintentionally reaches areas outside the target area, either as droplets, dry particles or vapour, during or after application on the target area (Carlsen *et al.*, 2006). Drift can be deposited on nearby soil or water surfaces, or on vegetation. Drift from the application of crop protection products can cause damage to neighbouring crops, ecosystems, and human health. The term 'pesticides' will be used hereafter as a generic term for crop protection products including herbicides, fungicides, insecticides, nematocides, et cetera.

Pesticide drift may occur in three ways (Robinson, 1990):

- *Spray drift*
  This is the result of the smaller drops in the spray being carried-off during spraying by wind or convection currents. Spray drift is the most common form of drift.
- *Vapour drift*
  This occurs when the vapour from a volatile pesticide is carried away from the target area during or after spraying. It is most likely to occur when spraying at high temperatures, with volatile active substances and where atmospheric and ground terrain conditions are conducive to the accumulation of vapour pockets (Miller, 2003). Most of the formulations registered in western countries have relatively low vapour pressures and vapour drift is therefore not a great concern here (Miller, 2003).
- *Blow*
  This is the movement by wind of dried spray particles or of soil impregnated with the pesticide away from the treated area. This type of drift is rare and only occurs under special conditions.

Relatively little work has been done on quantifying vapour drift and blow (Gil & Sinfort, 2006), presumably because vapour drift and blow are less important than spray drift. In this report, we focus on spray drift. Drift is usually referred to as a percentage of the applied dose to the crop.

The aim of this report is to provide estimations of spray drift for situations that occur in Chinese agricultural systems. Knapsack sprayers make up the prime tool for applying crop protection products in China, where this type of sprayers is used on 75% of the agricultural area farmed by smallholder farmers (He *et al.*, 2004). Other spray equipment used in China includes mistblowers, tractor mounted field sprayers and cart sprayers (Herbst & He, 2008). Apart from the benefits of pesticide use for agricultural production, spray drift can be a threat to the sustainability of farming and is a major source of pollution in China. Apart from ecological and agricultural problems associated with pesticide drift, Chinese farmers suffer directly from pesticide applications. According to research at the China Agricultural University in Beijing, 74% of the Chinese farmers have suffered poisonings after mixing and spraying pesticides in the past (He *et al.*, 2004). Such data stress the urgent need for reducing pesticide drift and improving application equipment and methods. An environmental risk assessment of the pesticides used in china can form an important contribution towards reducing the impacts from pesticide drift.

The results of this report will be used to model pesticide drift and conduct an environmental risk assessment of pesticides in Chinese agricultural systems, as part of the Sino-Dutch Pesticide Environmental Risk Assessment Project PERAP. This project includes a range of Dutch and Chinese partners, such as Wageningen UR (the Netherlands), ICAMA (China), and the Chinese Academy of Agricultural Science. The goal of this broader project is to support ICAMA with the inclusion of environmental risk assessment methodologies and criteria in the pesticide registration procedures in China and to form a local science platform that is able to support the regulators with scientific advice in the future.

2. Factors affecting drift from knapsack sprayers

2.1 Knapsack and mechanised sprayers

Most research on pesticide drift focussed on assessing spray drift in relation to droplet size, nozzle type and weather conditions through field studies and simulation modelling in highly mechanised agricultural systems. In these systems, knapsack sprayers usually only play a marginal role. The factors affecting drift from pesticide application using a knapsack sprayer are not principally different from those in highly mechanised agricultural systems. Under specified conditions, spray drift from a knapsack sprayer is more or less similar to that from other sprayers. However, with a knapsack sprayer, the variability in drift and the total drift in the field could be higher than in tractor spray applications because of the difficulty to maintain a constant spraying pressure, a constant spraying height and spraying angle, and other factors related to the operator's care, attitude and skills. Also the state of the equipment is often poorer with knapsack sprayers than in more mechanised systems. However, this is not related to the knapsack sprayer as such, but to the fact that knapsack sprayers are more frequently used by smallholder, resource-poor farmers. A knapsack sprayer that adheres to certain minimum standards, operated by a well-trained person, should not produce more drift than a more mechanised sprayer under similar conditions (i.e. similar weather conditions, nozzle type, spraying pressure, et cetera).

Figure 1a Spraying potatoes with a tractor-pulled boom sprayer in the Netherlands.

Figure 1b. Demonstration of a knapsack sprayer in Nigeria.

2.2 Factors that impact drift

The main factors affecting drift can be summarised as (Nuyttens *et al.*, 2006a, 2006b & 2007; Carlsen *et al.*, 2006; Gil & Sinfort, 2006):

1. Weather conditions (wind speed, temperature, relative humidity, atmospheric stability).
2. Application factors (sprayer type, nozzle type and size, spraying pressure, application height and angle).
3. Formulation (additives, density, and viscosity).
4. Operator care, attitude and skill.
5. Composition and state of the vegetation in the field and in field margins.

Below we provide more detailed information on factors affecting drift in general and from knapsack sprayers in particular.

1. *Weather conditions (wind speed, temperature, relative humidity, atmospheric stability).*
   Drift potential increases with wind speed. An increase in wind speed from 3 m s^{-1} to 5 m s^{-1} (at 2 m height) can double spray drift deposition (Holterman *et al.*, 1997). As a general rule, spray applications can be made in wind up to 6-8 km h^{-1} or 1.6-2.2 m s^{-1}, which gives a moderate tree leave movement (Miller & Bellinder, 2001). Completely wind still weather, on the other hand, enhances vapour drift and is not ideal for spraying. A low relative humidity strongly increases the amount of drift due to the effect of evaporation reducing the droplet sizes. High temperatures (> 25 ^{0}C) combined with a low relative humidity also makes droplets more susceptible to drift due to evaporation. On the other hand, at a constant relative humidity, higher temperatures actually reduce spray drift (Nuyttens *et al.*, 2006a). An increase in relative humidity from 40% to 90% can decrease drift from 13% to 3% at 1 m distance from the field (Nuyttens *et al.*, 2006a).

2. *Application factors (sprayer type, nozzle type and size, spraying pressure, application height and angle).* Most nozzles spray a wide range of droplet sizes. The composition of this droplet spectrum is one of the most important factors determining the amount of drift. Small spray droplets are much more likely to drift than large ones. Small droplets are more easily moved by wind. A high spray pressure will create a greater number of small droplets (Miller & Bellinder, 2001). Moreover, nozzle type has a strong impact on droplet size. Mean droplet size may vary with a factor 3 between different nozzles at a similar spraying pressure (Nuyttens *et al.*, 2007). The variation in drift between different nozzles under standard weather conditions can be even larger (Nuyttens *et al.*, 2006b). Especially the volume fraction of drops smaller than 100 μm in the spray fan are most vulnerable for spray drift. The fraction of these drops in the spray volume can be used as a first estimation of drift sensitivity of a nozzle.

   To minimise the fraction of small droplets in a spray cloud, low spraying pressure and large nozzle openings are required. However, in some cases, it is not desirable to have only large droplets. Small droplets increase spray coverage and can be a requirement for the effective application of certain fungicides, insecticides or certain contact herbicides. In this case, avoiding the impact from other factors enhancing drift becomes important (Miller & Bellinder, 2001). Nozzle type also affects the spraying angle, which on its turn may have an impact on drift (De Snoo & De Wit, 1993). Adaptations to knapsack sprayers can greatly reduce drift. For example, a drift shield attached to the lance of a knapsack sprayer can reduce target drift up to 63% (Awadhwal *et al.*, 1991).

3. *Formulation (additives, density, and viscosity)*.
   Pesticide formulations including the surfactants and additives have an impact on drift. The application of volatile pesticide formulations results in a relatively high amount of drift. Polymers and emulsifiable oils can be used as drift retardants by increasing droplet size and some adjuvants can be used as an anti-evaporant (De Ruiter *et al.*, 2003). See for details Holterman et al. (1998), De Ruiter *et al.* (2001) and Hewitt *et al.* (2001) showing the effect of formulation on spray drift and on volatilisation.

4. *Operator care, attitude and skill.*
   When spraying with a knapsack sprayer, skills of the operator are relatively important, compared to more mechanised spray equipment. For example, when a knapsack sprayer with a single nozzle boom is used in a swinging pattern across a field, as is often the case, the application result can be poor and drift relatively high. Also spray height and angle can greatly vary between operators of knapsack sprayers, which affects drift (De Snoo & De Wit, 1993). Drift increases with larger spray angles. Furthermore, greater spray heights increase drift (Jong *et al.*, 2000) as the trajectory time of the pesticide between the nozzle and the target increases.

5. *Composition and state of vegetation in the field and in field margins*.
   Vegetation in field margins can have a strong filtering effect and reduce drift (Van de Zande *et al.*, 2000a; Carlsen *et al.*, 2006). Hedgerows along field edges, for example, capture a great deal of the spray drift, which may lead to a reduction in spray drift of more than 73% (Lazzaro *et al.*, 2008) and even up to more than 90% when fully in leaf, depending on tree variety, leaf thickness and period during the growing season (Wenneker &

Van de Zande, 2008). There is also a crop edge effect on spray drift. It clearly makes a difference whether spray drift is quantified spraying a bare soil surface area or short cut grass compared to a fully developed field crop, with less drift occurring in a fully developed field crop.

Nozzle type is generally recognised as one of the key factors affecting droplet size and thus the amount of drift (Nuyttens *et al.*, 2007). The most common nozzles used in combination with knapsack sprayers are (Miller & Bellinder, 2001):

- *Flood or cut nozzles*
  These are designed to have a wide spraying pattern at low pressure making them popular with knapsack sprayer applications. The spray pattern is tapered from the centre to the edge.
- *Flat fan nozzles*
  These are designed specifically for multiple nozzle booms. The spray pattern is tapered from the centre (full flow) to the edges (lighter flow) and is designed to overlap with adjacent nozzles, creating a uniform pattern across a spray boom.
- *Even fan nozzles*
  These are designed for single nozzle pass sprays over crop rows or between rows of vegetable or plantation crops. The spray pattern is uniform from edge to edge, but are not made for multiple nozzle booms.
- *Variable cone nozzles*
  These have a cone-shaped spraying pattern that is adjustable from a fine mist to a solid stream. This adjustable pattern makes variable cone spray tips versatile tools, but calibration of these nozzles is not easy.
- *Hollow cone nozzles*
  These spray tips produce a fine spray that is concentrated on the outside edge of the pattern. The spray approaches the target from different angles increasing its coverage.

Among these nozzles, hollow cone and variable cone nozzles adjusted to create a fine spray have the highest drift potential, because of the fine droplet size (Miller & Bellinder, 2001). However, with similar droplet sizes, flat fan nozzles can create more drift than cone nozzles from a knapsack sprayer, because flat fan nozzles have a larger spray angle (De Snoo & De Wit, 1993; De Snoo, 1999). Flood nozzles have a wider spray angle than flat fan nozzles, which may also result in a high drift. Within each type of nozzle, the drift potential may vary a lot between nozzles. Drift reducing nozzles are available for all types of nozzles and these can reduce drift with 50-95%, compared with standard nozzles.

2.3 Drift reducing measurements

With a combination of measurements, drift in the field can be greatly reduced. Briefly, measurements that could be effective in reducing pesticide drift include:

1. Knapsack sprayer quality
   Ensure that only sprayers are used fulfilling the international ISO requirements for knapsack sprayers (ISO 22369-2; ISO, 1998) (Herbst *et al.*, 2006). The ISO standards provide guidelines with regard to the sprayer's weight, fixation points, spray tank, tubes, filters, nozzles, pressure gauge, et cetera.
2. Drift shields
   The use of a drift shield attached to the lance of a knapsack sprayer can greatly reduce drift. With a shield, drift reductions of 63% have been recorded (Awadhwal *et al.*, 1991).
3. Nozzle type
   Differences in drift between nozzles under standard conditions can be very large. Reductions in spray drift up to 75-90% have been achieved by using drift-reducing nozzles, relative to a reference situation (Nuyttens *et al.*, 2006b; Van de Zande *et al.*, 2008; ISO, 2006).
4. Operator skills
   Operating a knapsack sprayers requires a training input that is often lacking (i.e. calibration, equipment handling, timing of spraying, et cetera) (Herbst & He, 2008). Providing training to the knapsack operators can be highly effective in reducing drift. Training can also assist in reducing other sources of environmental pollution

from pesticides, for example by improving the storage of pesticides, methods for sprayer cleaning, or the handling of pesticide leftovers.

5. Field lay-out
   A crop-free, non-sprayed buffer zone can greatly reduce spray drift. For example, the creation of a 3 m spray free buffer zone can reduce drift in an adjacent ditch by 95% (De Snoo & De Wit, 1998; De Snoo, 1999), which is comparable to the 70% drift reduction found by Porskamp *et al.* (1995) by the creation of a 2.25m spray free zone. A crop-free zone with a high and dense vegetation is more effective in decreasing drift than bare soil (Carlsen *et al.*, 2006; Van de Zande *et al.*, 2000a; Wenneker & Van de Zande 2008).
6. Band spraying
   The drift caused by a band sprayer can be 90% less than that of a conventional field sprayer. This drift reduction can be achieved with both a single nozzle and a dual nozzle version per crop row (Van de Zande *et al.*, 2000b).
7. Boom height
   Lowering the sprayer boom height, i.e. reducing the distance between the nozzle and the crop canopy, assists in reducing spray drift. Lowering sprayer boom height from 70 cm to 30 cm above the crop canopy can result in a 80 % drift reduction (Jong *et al.*, 2000; Van de Zande *et al.*, 2008).
8. Orchards
   The use of tunnel sprayers or cross-flow fan sprayers with reflection shields can reduce drift in orchards by respectively 85% and 55% (Huijsmans *et al.*, 1993). Also in orchards, a crop free, non-sprayed buffer zone, possibly with vegetation on it, assists in reducing spray drift.

3. Quantifying drift from knapsack sprayers

3.1 ISO classifications and drift

The quantification of drift can be done in the field, in more controlled experimental setting such as wind tunnels or laboratoria, or through modelling (Holterman *et al.*, 1997; Porskamp *et al.*, 1999; Walklate *et al.*, 2000; Ganzelmeier & Rautmann, 2000; Van de Zande *et al.*, 2002). Because of the many factors that influence drift, the impact from spraying equipment or practices on drift rates is usually assessed under standardised conditions. These standards define spraying height, acceptable weather conditions, et cetera. Only under standardised conditions, the impact of drift reducing equipment can be quantified, classified into drift reducing categories and compared with each other. No standard conditions for measuring drift have been defined for Chinese conditions, as far as we are aware.

ISO, the International Organisation for Standardization, has defined international standards for measuring drift (ISO/FDIS 22866; ISO, 2005a), drift reduction classes for spraying equipment and how to evaluate these classes (ISO/FDIS 22369; ISO, 2006 and ISO/FDIS 22369-2; ISO, 2008), and requirements, test methods and performance limits for knapsack spraying equipment in order to ensure safe use (ISO/FDIS 19932-2; ISO 2005b). International standards for field measurements of spray drift (ISO, 2005a) establishes principles for the measurement of droplet drift from all types of equipment designed for applying pesticides. Furthermore, ISO classification recognises various drift reduction classes, in comparison with a reference nozzle under specified conditions (ISO/DFIS 22369). The ISO classification recognizes nozzle drift classes of 50%, 75%, 90%, 95% and 99% drift reduction. The ISO classification of requirements, test methods and performance limits for knapsack spraying are useful for setting minimum standards to which knapsack sprayers in the field and those that are newly produced should adhere (ISO/FDIS 19932-2).

3.2 Knapsack sprayers in China

Knapsack sprayers used by resource-poor farmers are often outdated and in poor condition, with a great deal of sprayers leaking from the nozzle or the trigger valves (Matthews, 2008). In a survey among approximately 300 smallholder farmers using knapsack sprayers in China, it was found that a great deal of the knapsack sprayers did not agree with the requirements defined by international standards (Herbst *et al.*, 2006; Herbst & He, 2008). Many knapsack sprayers did not have a pressure gauge or a pressure control and hence, it was impossible to calibrate the sprayer or control the sprayer output rate during application. Many of the sprayers leaked and contaminated the operators which can lead to health problems. Moreover, the operators did not clean the sprayer after application and dumped the chemical residues into the waste water system. Pesticide losses due to poor spraying equipment and careless pesticide handling methods are not included when assessing drift with the help of spray drift curves, as we have done below. However, such losses can be significant sources of pesticide pollution and should be avoided as much as possible.

Most common nozzles in China used in conjunction with knapsack sprayers are the hollow cone and variable cone nozzles, which together account for about 90% of all nozzles used (Herbst & He, 2008).

3.3 Estimating drift

Drift is usually presented using relative drift (percentage of the applied dose) as a function of distance from the crop edge. The amount of drift declines exponentially at larger distances from the sprayed area. Spray drift at larger distances (> 5 m) from the field tends to be very small (less than 3%) (Nuyttens *et al.*, 2006a), but is relevant when non-target organisms further away from the field are highly sensitive to the applied pesticides.

China harbours a range of farming systems with different agro-ecological zones, crops, field management, et cetera and standard conditions for measuring drift in the various agro-ecological zones of China have been specified, as far as we are aware. Moreover, we have not been able to retrieve data in the literature on actual measurements of spray drift in China. Therefore, to estimate drift curves that can be applied to Chinese conditions; we have used data from collected outside China, combined with a modelling study using parameters that can be representative for Chinese conditions.

3.3.1 Simulations of drift on bare soils

Simulations of the downwind off-target spray drift were carried out with the help of the IDEFICS spray drift simulation model. Both ground-deposited drift as well vertical distributions at four distances downwind: 5, 10, 15 and 20 m from the edge of the crop, were calculated.

The following settings were used in the simulations:
- Nozzle type: flat fan XR11004 (a standard nozzle without particular drift reducing properties)
- Liquid pressure: 200 kPa
- Distance between walking paths: 1 m
- Outer nozzle located 0.5 m from crop edge (i.e. upwind from crop edge)
- Height of sprayer boom: 1 m above ground level (regardless of crop height)
- Walking speed: 1 m s^{-1} (3.6 km h^{-1}), parallel to the border of the field
- Wind speed 3 m s^{-1} (measured at height 2 m above bare soil); wind direction perpendicular to edge of field

Four crop/weather types were selected:
1. Crop height 5 cm, a warm and humid climate (e.g. rice fields in southern China): Temperature 30°C, Relative Humidity 80%.
2. Crop height 50 cm, the same warm and humid climate.
3. Crop height 5 cm, a cold and dry climate (e.g. dry land agricultural in northern China): Temperature 15°C, Relative humidity 40%.
4. Crop height 50 cm, the same cold and dry climate.

The combination of nozzle type, liquid pressure, walking speed and distance between walking paths results in overall dose rate of 215 l ha^{-1}.

Simulations were carried out using IDEFICS version 3.51. All results represent droplets and dried particles combined. Results are given as percentage of the dose applied onto the crop.

The results of the simulations indicated that downwind deposits were lower when a crop of 50 cm height was present, compared to a crop of 5 cm (Figure 2). The distance between nozzle and crop canopy clearly has a strong impact on the amount of drift. In the selected cold and dry environment, the dry air enhanced evaporation, resulting in decreasing drop sizes while they were still airborne. These smaller drops tended to flow farther downwind before depositing onto the ground. As a result, ground deposits further away from the field (> 1 m) were higher in the cold and dry region than in the warm and humid region. Though low air temperature reduced evaporation, the effect of relative humidity was apparently stronger than the effect of temperature, in the selected situations.

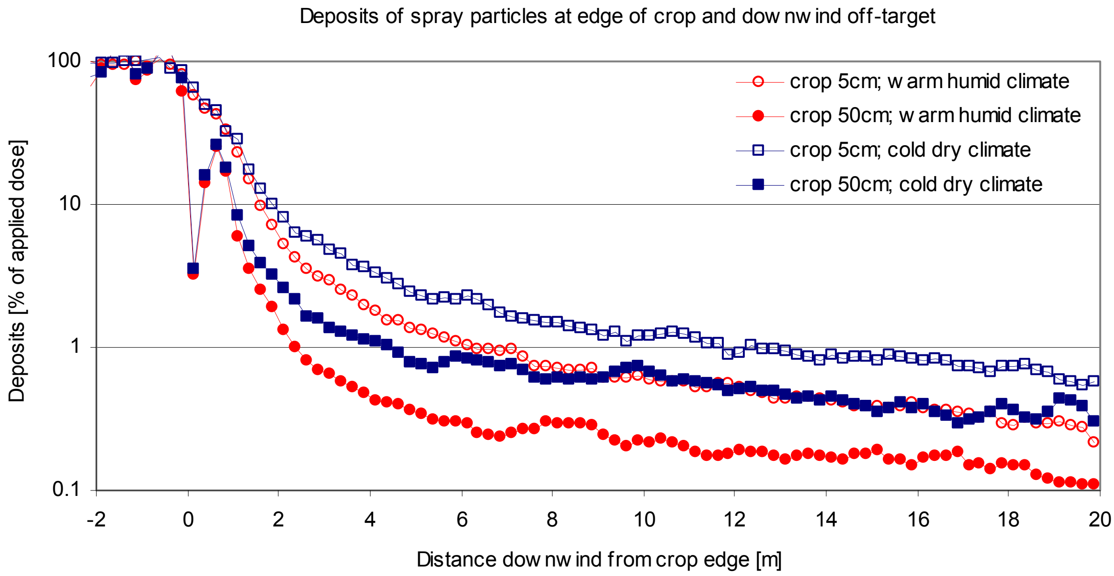

Figure 2. Ground deposits as a function of distance from the crop edge, simulated by the IDEFICS model.

The total amount of airborne spray decreased with increasing downwind distance, as part of the spray is deposited onto the ground while moving farther downwind (Figure 3). With increasing distance from the field, a greater proportion of the drift was deposited on the ground, leaving less spray in the air. Similar to the effects described above for ground deposits, in cold and dry circumstances the amount of airborne spray was higher than in warm and humid circumstances, as droplets tended to be smaller in the cold and dry climate and smaller droplets tend to drift further away from the crop edge than large droplets. Also, with a crop height of 50 cm, the amount of airborne spray was lower than when the crop was only 5 cm high, as a greater proportion of the spray was deposited on the crop when crop height was 50 cm.

The IDEFICS model does not account for factors related to the skills and habits of the pesticide applicator. For example, a single nozzle spray lance is often used in a swinging pattern. This could lead to more drift than the application of pesticides with a nozzle boom held steadily, which the situation is presumed by the IDEFICS model. In the next section, we therefore show some results of field measurements of drift from knapsack sprayers.

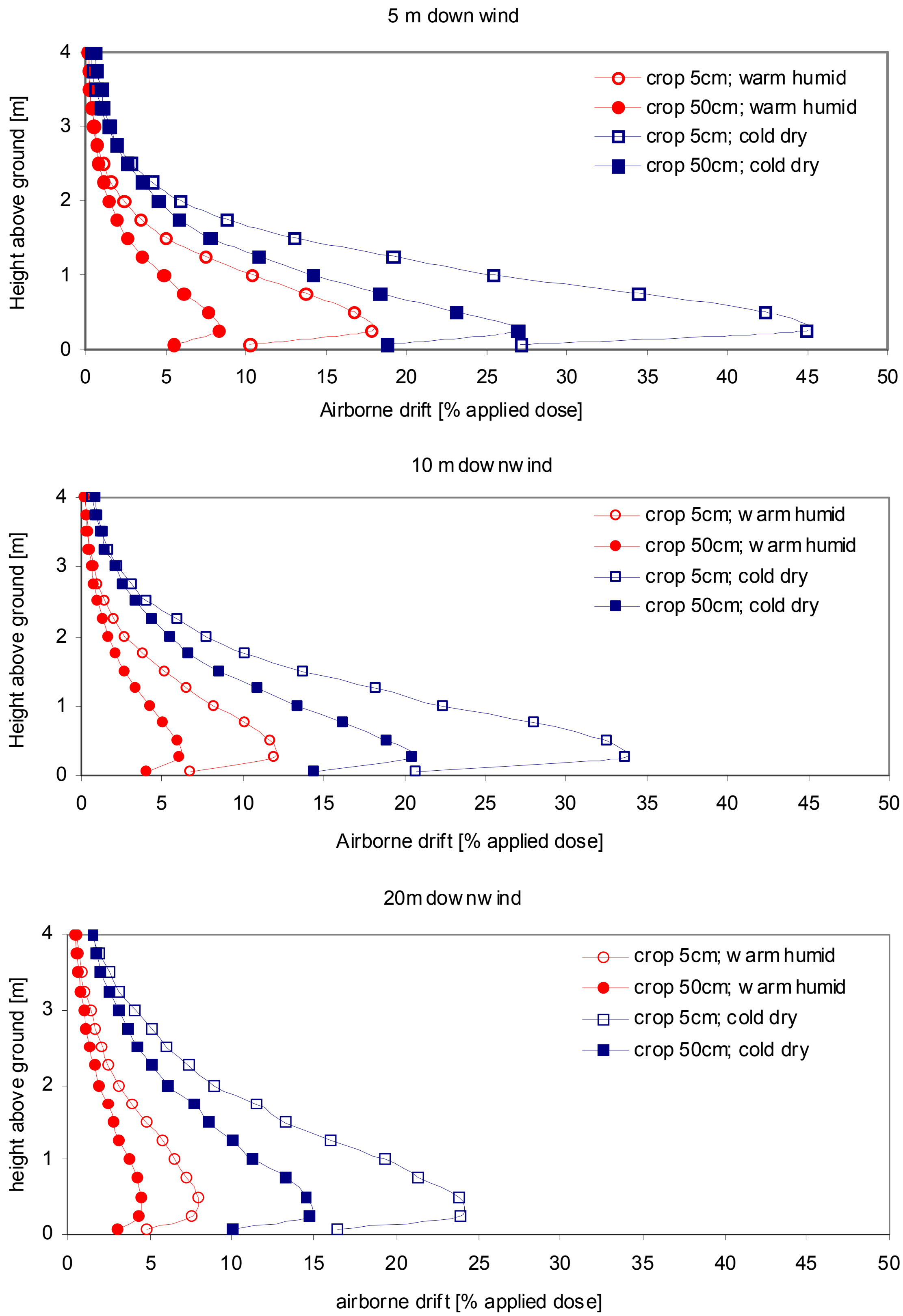

Figure 3. *Vertical distribution of airborne spray downwind at 5 m, 10 m and 20 m from the crop edge, simulated by the IDEFICS model.*

3.3.2 Simulations of drift mulberry trees

Estimations of drift on mulberry trees is relevant for the Chinese situation, as the protection of the sensitive silkworm, fed with leaves from the mulberry tree is important in Chinese agriculture. Figure 4 shows the reference situation.

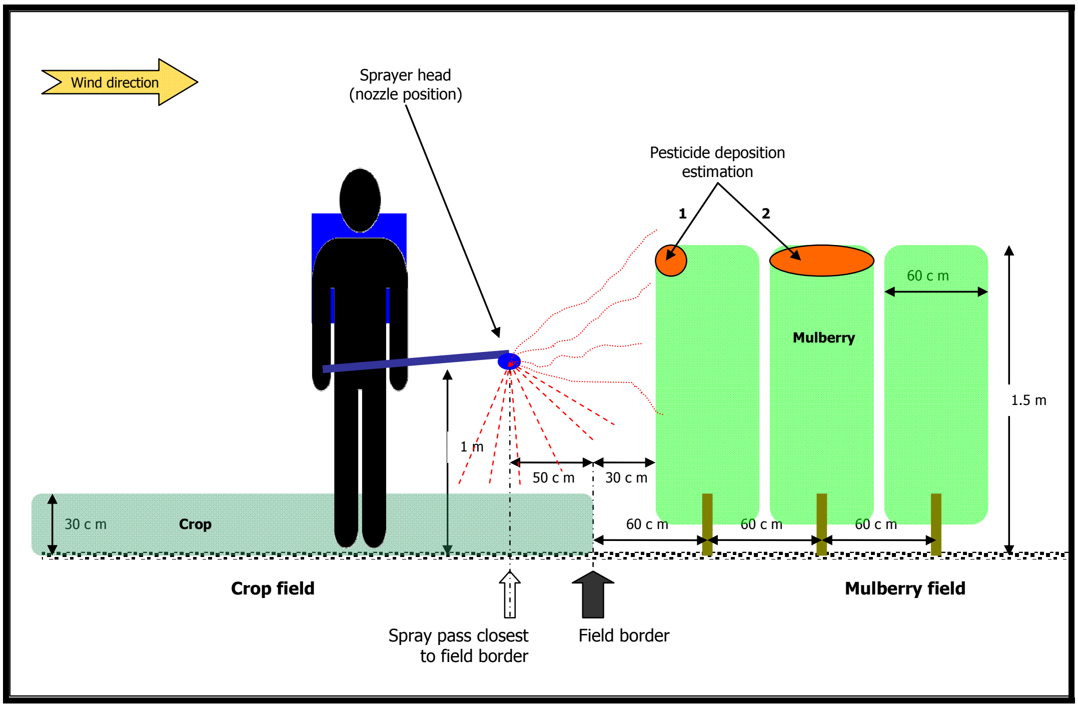

Figure 4. Reference situation for estimating the spray drift on mulberry trees.

Simulations were carried out using the IDEFICS spray drift model.
General settings:
- nozzles XR11008 flat fan
- liquid pressure 300 kPa
- walking speed 0.70 m/s
- distance between walking paths: 1.00 m
- spray height above ground level: 1.00 m
- height of sprayed crop: 0.30 m
- outer nozzle position; 0.50 m upwind from crop edge
- wind speed: 3.0 m/s (measured 2.0 m above a grass plain)
- wind direction: perpendicular to crop edge
- atmospheric stability: neutral

The combination of nozzle type, liquid pressure, walking speed and distance between walking paths gives an applied dose of 750 l/ha (or 75 ml/m^2).

Four climatic conditions were simulated, based on menthly climate data in the silk producing zones of China:
1. temperature 20°C, relative humidity 40%
2. temperature 20°C, relative humidity 80%
3. temperature 32°C, relative humidity 60%
4. temperature 32°C, relative humidity 85%

Figure 5 shows an estimate of vertical distribution of spray drift, next to the sprayed field. In fact this corresponds to the deposits on the frontal side of the first mulberry tree.

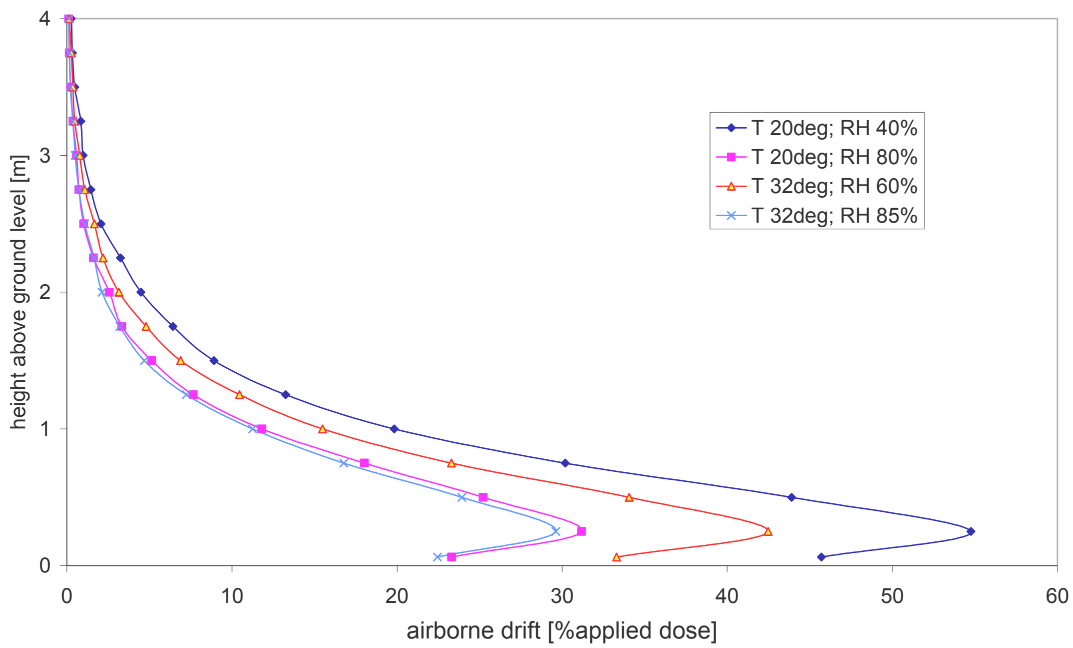

Figure 5. *Estimate of vertical distribution of airborne spray at the frontal side of the first mulberry tree.*

At the top 10 cm of the frontal side of the first mulberry tree, i.e. at height 1.4-1.5 m, the average deposits are given in Table 1. The part of the spray cloud distribution given in Fig.1 that is above the mulberry trees will flow farther downwind, while spreading by diffusion. Due to this diffusion, the spray cloud will partially deposit onto the top of the mulberry trees. Estimates of these deposits for the first and second row of mulberries are shown in Table 1 as well. Data are given as percentage of applied dose, and for a known dose of 75 ml/m^2, the deposits are shown as ml/m^2 as well.

Table 1. *Estimated deposits (as % of applied dose) on mulberry trees adjacent to a sprayed crop field.*

Location	Unit	T 20; RH 40	T 20; RH 80	T 32; RH60	T 32; RH 85
Frontal side 1.40-1.50m high	[%dose] [ml/m^2]	9.8 7.3	5.6 4.2	7.6 5.7	5.2 3.9
Top of first mulberry	[%dose] [ml/m^2]	1.82 1.36	1.07 0.80	1.46 1.09	1.08 0.81
Top of second mulberry	[%dose] [ml/m^2]	0.61 0.46	0.35 0.26	0.48 0.36	0.35 0.26

Thus, the vertical frontal side of the first mulberry row is exposed most to spray drift. The top sides of both first and second mulberry row receive much less spray deposits. Typically, the top of the second row appears to receive about 1/3 of the spray depositing on the top of the first row, irrespective of the weather conditions.

3.3.3 Field measurements of drift from knapsack sprayers

Drift from knapsack sprayers in rice fields in the Philippines, under on-farm conditions with the sprayers operated by farmers, was measured by Snelder *et al.* (2008) (Figure 6). In this study, 22 farmers used their own sprayers and nozzle equipment in rice fields and applied pesticides in their usual way (i.e. by waving the nozzle from side to side in front of them). Farmers used flood nozzles from different manufacturers. The crops in the field were 20 to 60 cm high and spraying was done at a wind speed of less than 1 m s^{-1}, except for one case. This situation may be fairly representative for the Chinese situation under warm and humid conditions, i.e. for rice fields in southern China. The results showed that at 0.5 m from the field boundary, pesticide drift was on average 12% of the applied dosage, falling to about 2% at 1.5 m - 2.0 m from the crop edge.

The levels of drift in the Philippines reported by Snelder *et al.* (2008) are within the range found by De Snoo & De Wit (1993) for drift from knapsack sprayers in the Netherlands. In this study, cone and flood nozzles were used at a wind speed of 2.5-3.5 m s^{-1}, a pressure of 2 bar, a spray height of 15-30 cm on bare soil. Drift was measured in a ditch directly adjacent to the crop field. The drift, at 0.6 m downwind from the field varied between close to zero and 10% of the applied dose. At 0.9 m downwind from the field, drift equalled 3% or less. Nozzle type was found to have a strondg impact on drift. Flood nozzles gave much more drift than cone nozzles. Drift rapidly increased at wind speeds of more than 4 m s^{-1}.

Van Kammen *et al.* (1998) measured the drift of a boom sprayer typically used in nursery trees in the Netherlands. Flat fan nozzles and a spraying pressure of 3 bar were used. The drift percentage under standard condition (without drift reducing measurement) at 0.5 m downwind from the crop edge was found to be about 3%, at 1 m it was 2%, at 2.5 m it was 1 % and at > 2.5 m it was less than 1%. The use of a spray shield attached to the spray boom reduced drift by roughly 50%. The use of a curtain at the crop edge further reduced drift to only a small fraction of the drift found under standard conditions.

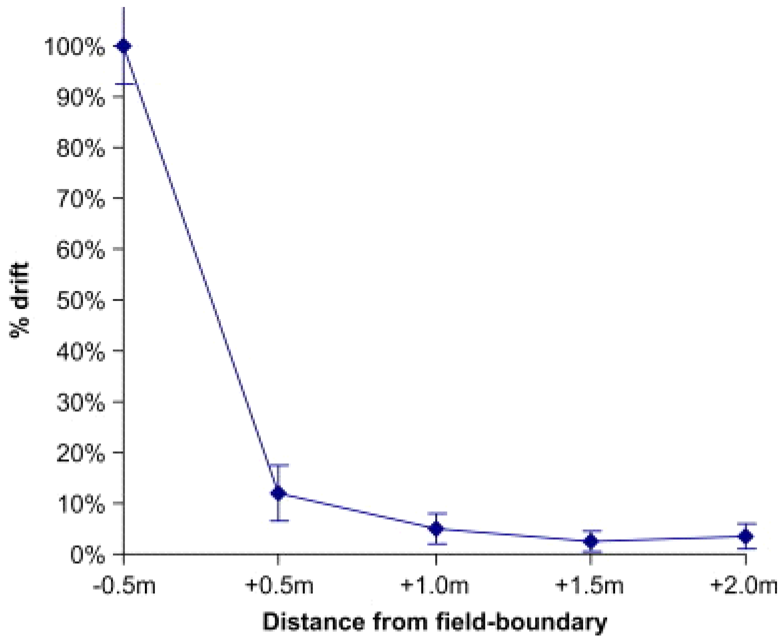

Figure 6. Pesticide deposition from knapsack sprayers in rice in the Philippines, expressed as the percentage of the applied dosage per unit area, average from 17 farmers (source: Snelder et al., 2008). Error bars represent the standard deviation of the mean.

3.3.4 Comparing field and simulation data

A comparison of the field data from literature with the simulated drift figures shows that the highest ground-deposited drift was observed in the simulations with a crop height of 5 cm (Table 2). In this scenario, the distance between crop canopy and sprayer boom was largest, leading to very high drift figures. This amount of simulated drift can be realistic under poor spraying conditions, but is unlikely to occur under average conditions.

When the crop height was set at 50 cm in the simulation studies, much lower drift figures were found. In this case, the simulated drift was comparable with the figures found in the field studies. With the exception of the simulated drift data with a crop height of 5 cm, overall down wind drift at 1 m from the crop edge was below 10%, at 2 m or further from the crop edge drift was 3% or less, at 5 m or further from the crop edge drift was less than 1% of the applied dose.

The drift figures retrieved from rice farmers in the field (Snelder *et al.*, 2008) was comparable with the simulation with a crop height of 50 cm in a warm and humid climate, especially at 1.0 and 2.0 m. Although farmers may handle knapsack sprayers during pesticide application in various ways (e.g. by waving the nozzle from side to side in front of them), this did not lead to drift figures that were very different from those obtained by the simulation model, which assumes a uniform way of application.

The particular conditions defined in the model simulating drift on mulberry trees cannot be compared with any field data we are aware of.

Table 2. Ground-deposited drift and air-borne spray downwind from the crop edge measured in various studies (% of the applied dose).

Down wind distance from crop edge		0.5 m	1.0 m	2.0 m	5.0 m	10.0 m	20.0 m
Philippines [1] - ground deposits							
Farmers' rice fields		12	5	2-3			
Netherlands [2] - ground deposits							
Bare soil, flat fan nozzle		12	3				
Simulated - ground deposits							
Crop height 5 cm, warm and humid		42	23	5.3	1.3	0.6	0.2
Crop height 50 cm, warm and humid		25	5.9	1.3	0.3	0.2	0.1
Crop height 5 cm, cold and dry		45	28	8.2	2.3	1.2	0.6
Crop height 50 cm, cold and dry		26	8.2	2.6	0.8	0.7	0.3
Simulated - airborne spray							
Crop height 5 cm, warm and humid	1 m above ground				6.4	4.0	1.9
Crop height 50 cm, warm and humid	1 m above ground				1.5	1.0	0.4
Crop height 5 cm, cold and dry	1 m above ground				8.3	4.4	1.3
Crop height 50 cm, cold and dry	1 m above ground				1.7	0.9	0.2
Crop height 5 cm, warm and humid	2 m above ground				1.4	1.3	0.9
Crop height 50 cm, warm and humid	2 m above ground				0.4	0.3	0.2
Crop height 5 cm, cold and dry	2 m above ground				1.5	1.3	0.6
Crop height 50 cm, cold and dry	2 m above ground				0.4	0.3	0.1

[1] *Source: Snelder et al. (2008).*

[2] *Source: De Snoo & De Wit (1993).*

5. Literature

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