Landesanstalt für Pflanzenbau und Pflanzenschutz, Mainz

The patchiness of pesticide drift deposition patterns in plant canopies

Heribert Koch, Oliver Strub, Peter Weißer

Abstract

To visualise drift of pesticide application, 4 l/ha Gramoxone Extra (100 g/l Paraquat) was applied with a plot sprayer under the following conditions: wind velocity 7 m/s; nozzle XR 110 02 at 200 l/ha producing approx. 10 % of delivered volume in droplets < 100µm. High wind speeds tend to exacerbate drift and extend the expected drift gradient. Paraquat destroys chlorophyll and demonstrates the deposition patterns of drifted droplets as chlorotic areas on green leaf surfaces. The droplet transport in time, as well as their speed and direction is dependent on air movement as soon as the droplets have lost their kinetic energy. Drifting particles are retained once they impact on any solid surface. The retention process of drift particles is quite different from the retention of the original spray. Spray droplets may be reflected, shatter or run off. Drift is a stochastic process occurring in seconds and results in a broad variation of deposits on individual leaves due to fast changes of wind direction and wind speed and turbulence. The shape of the deposition gradient (macro deposition) varies within short distances. This pattern was visualised by the typical bleaching effect of Paraquat. Drifting particles are mainly retained in the upper zone of a canopy according to wind and air movement and rarely penetrate into lower canopy regions. This leads to a spatial distribution pattern with a patchy deposit variation in both the vertical and horizontal expansion of the canopy. The micro deposition pattern is characterised by very low coverage of plant surfaces, depending on the number of droplets < 100 µm in diameter which is ecotoxicologically more relevant than the Paraquat affected leaf area. Upper plant parts intercept more drifting particles than the plant base in a canopy. Modern nozzle designs reduce the drift potential to less than 0,3% at appropriate pressures. The visualised micropatchiness gave an impression of the deposition variability from leaf to leaf as well as within the canopy. Applications done under calm conditions demonstrate the potential of drift reduction of such nozzles. The patchy distribution should be recognised in any risk assessment. Under calm conditions the drift reducing potential of the air induction nozzle results in a clear cut borderline to the unsprayed zone. The XR 110 02 creates a gradient of about 1m at the edge of the XR 110 02 treated plot due to the fine drop volume.

Key words: patchiness of drift deposition, pesticide drift, drift pattern, exposure to non target organisms, off-crop-habitat

Zusammenfassung

Um das Depositionsmuster von Abdrift sichtbar zu machen, wurden 4 l/ha Gramoxone Extra (100 g/l Paraquat) mit einem Parzellenspritzgerät bei einer Windgeschwindigkeit von 7 m/s appliziert. Bei 200 l/ha erzeugt die verwendete Düse XR 110 02 ein Feintropfenvolumem von ca.10 %. Durch Applikation bei sehr hoher Windgeschwindigkeit sollte Drift provoziert werden, so dass ein auseinander gezogener Gradient entstehen konnte. Paraquat zerstört Chlorophyll und läßt den von jedem einzelnen Partikel verursachten Fleck am Anlagerungspunkt sichtbar werden. Verdriftende Partikel sind < 100µm und lagern sich an jeder beliebigen Oberfläche an. Der Anlagerungsprozess schwebefähiger Partikel ist somit völlig anders als im Spritzbereich, wo es zum Zusammen- oder Abfließen angelagerter Tropfen kommen kann. Das im Bestand sichtbar gemachte Belagsmuster zeichnet sich kleinräumig durch große Variabilität aus. Dies wird als Macropatchiness bezeichnet. Verdriftende Partikel bewegen sich in der Luftströmung eine gewisse Strecke zunächst über dem Bestand bzw. in dessen oberem Bereich. Sie dringen praktisch nicht in tiefere Bestandeszonen ein. Dieses Verhalten führt zu einem Verteilungsmuster, das in der Bestandestiefe ebenso variiert wie in der flächigen Ausdehnung. Das Belagsmuster zeigt auch, dass der ökotoxikologisch relevante Bedeckungsgrad von Driftbelägen äußerst gering ist und auf den Blättern eine Micropatchiness erzeugt. Ergänzend zu der Applikation bei Wind wurde Paraquat mit der genannten Düse XR 110 02 sowie der Injektordüse ID 120 015 bei Windstille ausgebracht. Das driftreduzierende Potenzial der grobtropfigen Technik wurde erkennbar als randscharfe Behandlung, während die Variante mit ca.10% Feintropfenvolumen einen wenigstens 1 m breiten durch Tropfenverfrachtung verursachten Übergangsbereich entstehen ließ.

Schlüsselwörter: Patchiness von Driftbelägen, Abdrift, Driftbelagsmuster, Exposition von Nicht-Ziel-Organismen, off-crop-Habitat.

Introduction

Drift originating from pesticide application is a serious concern that has to be considered in both risk assessment and pesticide registration and requires pesticide handling on the farm according to “Good Agricultural Practice” (Anon, 1998). Requirements of the EU Guideline 91/414 have forced registration authorities of the member states to establish the protection of non target organisms from unacceptable effects. Today, a calculation-based , “conservative” system has been introduced which is assumed to consider a “realistic worst case” as stipulated by the EU-Guideline. But what is “conservative” or “realistic worst case”? The established exposure assessment, like the German “Basic Drift Values” (Ganzelmeier et al., 1995), is based on the BBA-Guideline VII – 2.1.1 (BBA, 1992). According to the guideline, petri dishes have to be used as artificial collectors for drift sediments, placed downwind on a field on bare ground. This drift scenario with bare ground away from the field is rather rare in practice. Drift sedimentation on plain bare ground is with respect to wind and air movement very different from drift deposition on a canopy which changes air speed and direction due to it’s roughness and structure.
Of course, such factors are difficult to describe, but they affect the drift process and need to be considered in a realistic risk assessment. It is obvious that drift sediments collected in petri dishes on a bare ground cannot describe the exposure on plant surfaces in an off-crop habitat. Any kind of recalculation suffers because the drift process as well as the retention process are different (Wolf, 1999; Koch et al., 2003). This paper describes activities to visualise drift patterns in canopies in order to demonstrate macro- and micropatchiness (Strub, 2002; Koch et al. 2002). This approach may be useful for a better understanding of drift processes and may be considered when drift measurements are interpreted.

Materials and methods

Our objective was to apply Paraquat under conditions of high wind (>7 m/s) in order to provoke drift and achieve an extended drift gradient. The application was done with a plot sprayer (Schachtner PSG-P5.2.04.S300F) equipped with 5 XR 110 02 nozzles (fig.1). At 1.9 bar, these nozzles deliver about 10 % of the spray volume in droplets less than 100 µm, thus having a high potential for drift. A commercial wheat crop was used, and 4 l/ha Gramoxone Extra was applied at label rate (4l/ha; 100g Paraquat/l) in a volume of 200 l/ha. Trials were also done in a meadow and in summer barley, although these are not reported here; however, these unpublished results support the conclusions reported here. The application/driving direction was aligned almost perpendicular to the wind direction. Boom height was adjusted to 50 cm above the canopy.

A second set of trials demonstrated the deposition pattern under calm conditions in order to exclude the factor air movement. We intended to demonstrate the clear borderline between sprayed and unsprayed area, under calm conditions. Differences between the standard flat fan nozzle XR 110 02 at 1.9 bar with a fine drop volume of about 10 % and the air induction nozzle ID 120 015 at 3 bar with a fine drop volume below 1 % were also compared. The tested nozzle boom configurations had been checked on a patternator before application in order to assure an appropriate horizontal distribution.

To demonstrate the size of the initially contaminated leaf surface at the retention site of drift particles a blue pigment dye was added to the spray fluid (Corante Azul; Duas Rodas Industrial Ltd). It was supposed that the blue dye would document the retained interface area of the liquid on the leaf at the time of retention.

Fig.1: Application with a Schachtner plot sprayer, wind speed 7 m/s. XR 110 02, 1.9 bar, 200 l/ha

Results

Deposition pattern under drift provoking conditions

The results of this work are primarily visual, i.e., pictures of drift deposition patterns in cereal crops and meadows. Fig. 2 shows the pattern of chlorophyll destruction induced by Paraquat, highlighting the typical drift gradient over distance. That gradient is documented, *e.g.*, in the German basic drift values (Ganzelmeier et al. 1995). Such figures are understood to summarise the drift process as a whole in the drift area. Clearly visible in fig. 2 are more or less affected areas resulting from trails of drift deposition. These drift trails document the variation of droplet deposition and give an impression of how fast wind velocity and wind direction are changing. The length of the marked plot is 10 m with a duration of the application of 10 s. The overall view in fig. 2 and 3 illustrates a pattern which we term the macropatchiness. It explains the variation of deposits at defined measuring distances as required for trials done according to the BBA-Guideline (BBA, 1992). In other trials, samples were taken along the indicated measuring distances at 1 m, 3 m, 5 m and 10 m downwind of the sprayed plot in order to quantify drift deposits on plant surfaces (Koch *et al.*, 2003). The effect of wind can also be seen at the weather side of the plot where the Paraquat symptoms are shifted towards the centre of the plot (fig. 2). This clearly shows that only fine droplets are transported by air movement. The majority of chemical is sedimenting out rapidly because of the mass and kinetic energy of each individual droplet, despite of air movement.

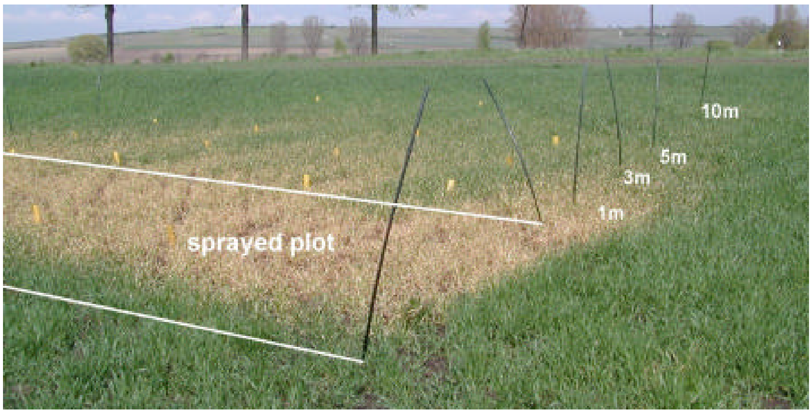

Fig.2: Sprayed plot and drift pattern in wheat 2 weeks after application. Chlorosis is induced by Paraquat.

Fig.3: Close up picture showing single spots induced by single particles less than 100 µm in diameter (wheat).

The close up picture (fig.3) illustrates Paraquat spots and visualises effects on single leaves (wheat). Drifted and retained particles tend to be smaller than 100 µm in diameter and do not alter their position after impact. They establish a spot due to the chlorotic properties of Paraquat: the affected area is much larger than the original in-flight droplet diameter. This deposition pattern on leaves is called the micropatchiness.
Alfalfa is a species which shows very clear Paraquat effects (fig. 4). The picture is taken from a drift trail in a meadow of about 30 cm canopy height. Single alfalfa plants of more than 50 cm height were more exposed and captured more particles.

Fig 4: Close up picture showing single Paraquat induced spots on alfalfa. Each dot is the result of a single droplet smaller than 100µm in diameter.

In the dense and very rough grass canopy, spotted Paraquat symptoms mainly occur on the top parts of the plants demonstrating that drifting droplets do not penetrate into the sheltered deeper zones (fig. 5). This effect is typical for grass dominated canopies like off-crop habitats, and raises the question of the actual exposure of non-target organisms, especially insects, within such canopies.

Fig.5: Paraquat spots on leaves of a grass canopy. Trial carried out in a set aside meadow with a very inhomogeneous and rough canopy. Particles do not penetrate into the deeper zone of high leaf density

Parquat induced spot size and contaminated leaf surface

Fig. 6 shows a section of a single leaf of reed (*Phragmites australis)* with several Paraquat spots 3 days after drift contamination. The spots can be several mm in diameter depending on the Paraquat load of the droplet and on plant surface/tissue characteristics. It would be possible to count the number of spots and assess approximately the amount of active ingredient deposited assuming a known maximum size of drifting droplets. There would be a difficulty correlating deposit area to original in-flight drop diameter. However, by observation alone, one can conclude that the leaf area covered by drifted particles is very small compared to the leaf area affected by Paraquat.

To demonstrate the particle size in comparison to the spot size a blue dye pigment was added to the spray fluid. The blue dye marked the contaminated position of the retained particle and indicates it’s original size. The difference between particle size and spot size is remarkable because Paraquat is a non systemic compound.

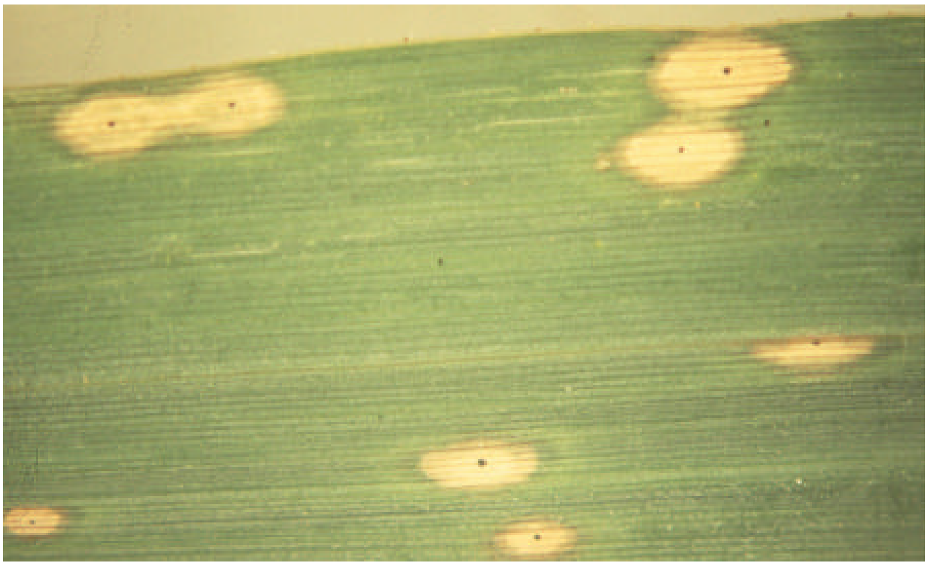

Fig.6: Single Paraquat induced spots on *Phragmites australis* showing the blue coloured original particle size

Deposition pattern under calm conditions

In a separate trial Paraquat was applied under calm conditions, comparing the deposition pattern of applications with high and low fine drop volume. Fig. 7 and fig. 8 give an impression of the application situation in wheat. The spray and the drift cloud of the XR 110 02 are clearly visible. The acceptable horizontal distribution is proved by checking the boom on a patternator and by full efficacy one week after application as shown in fig. 9 and 10. Both pictures show the expected effect of Paraquat within the sprayed plot. Much more interesting are the borders and the transition zone from the sprayed to the unsprayed area. While the air induction nozzle creates a clear cut borderline to the unsprayed zone, there is a gradient of about 1m at the edge of the XR 110 02 treated plot. This 1 m wide zone is produced by fine droplets, sedimenting uncontrolled in a random process (fig. 10). “Uncontrolled” means that the droplets do not follow a directed flight path between nozzle and impact position but float in the air and sediment elsewhere, depending on meteorological conditions.

Fig. 7: Application under calm conditions: ID 120 015, 3 bar, 200 l/ha

Fig. 8: Application under calm conditions: XR 110 02, 1.9 bar, 200 l/ha. In the background the meteorological pole, recording wind speed and wind direction

Fig 9: distinct separation of the sprayed area (ID 120 015, 3 bar, 250 l/ha)

Fig. 10: Even at calm is a clear gradient established, indicating the transition from sprayed to unsprayed (XR 110 02, 1.9 bar, 300 l/ha). In the back the plot shown in fig. 9.

Discussion

Our objective was to visualise how drift patterns on real undisturbed canopies can look like. These trials were not intended to quantify the deposits or to establish a relation to drift distance or other drift relevant technical parameters. Applications were done under meteorological conditions likely to give excessive drift (wind speed > 7 m/s) in wheat or a meadow. We also wanted to assure a wide drift zone with an extended drift gradient. This trial design should cover effects of the canopy itself on the expansion of the particle cloud as well as of turbulences of the air movement and finally the retention processes.
Paraquat was used, an active ingredient that destroys chlorophyll and triggers bleaching. Any drifting particle containing sufficient active ingredient will induce the typical chlorotic effect at the retention site. We have assumed that such small particles are not altered in position and size or shape after impact and drying.
Paraquat causes the chlorotic spots and thus makes the pattern of the scattered particle retention sites perceptible. Bearing in mind that droplets smaller than 100µm in diameter are prone to drift, we expect that any retained droplet will create a distinct single spot. The affected leaf area does not represent the original in flight size of the

droplet and is much larger than the area initially covered by one retained particle. The destruction of the green leaf area is visible on both sides of a leaf after some time. Nevertheless, the deposition pattern can be demonstrated. This pattern might be ecologically more important than static and distance oriented sediment figures alone, as they are currently collected from drift measurements, using artificial flat collectors placed downwind on bare ground or cut meadows (Ganzelmeier et al, 1995; Huijsmans et al., 1997).

Plant canopies affect air movement and deposition as well due to their roughness which has been figured out by Wolf (1999). The pictures clearly show the effect of the canopy structure on the drift process itself as well as on the retention pattern. The single droplet deposition pattern is characterised by a very low coverage. The Parquat induced spots are much larger than the original particle. A droplet of 100 µm in diameter may contaminate an area of 0,00785 mm² according to the size of the such a particles cross section, *i.e.* the percentage of the leaf surface area covered by droplets at the time of impact is very small in comparison to the coverage achieved by the spray application. In other words, the portion of plant surface not contaminated is large and gives plant dwelling insects space to hide or avoid any contact. Beside the deposit (ng/cm²) the covered leaf surface is another predominant factor of affect assessment.

While a large initial deposition area (coverage) is a key parameter of a spray application in order to establish the intended efficacy against pathogens (Siegfried et al., 1990) on the other hand, drift deposits are typically characterised by a very small portion of the plant surface contaminated. This in conclusion may result in low effects of drift deposits on populations of non target organisms when the drift potential is low as is indicated for new technologies (Koch et al., 2003).

The scattered particles are not randomly distributed but show a patchy pattern. This micropatchiness is characterised by a higher particle density in the top layer of the canopy and a wide variation in particle retention on a small scale. As the air moves predominantly through the top zone and above the canopy, drifting particles preferentially impact in the upper regions and do not penetrate deep down into the canopy (fig. 4).

The retention process of the spray is totally different from drift deposition (Koch et al., 2003). Earlier research work has shown how inhomogeneous the retention of sprays even on single leaves can be (Koch & Spieles, 1992). While droplets of a spray may be reflected and run off or run down into deeper zones of the canopy, drifting particles are retained on impact, totally depending on the actual air movement.

Off crop habitats look more like the grass structure in fig. 4 than the comparably open and well structured wheat crop in fig. 3. From the very small percentage drift covered leaf area and the micropatchiness of the scattered particles, ecotoxicologists and risk assessors may consider the probability of the contamination of non target insects and thus risks for populations. This assessment should include the potential to hide and escape from contamination as indicated by Kühne et al. 2002. Fig. 6 to 9 demonstrate clearly the behaviour of fine droplets in terms of retention and the potential of pressure/nozzle combinations to produce a low drift potential.

The volume delivered in droplets less than 100 µm is called the fine drop volume. Because of their low kinetic energy, such small droplets do not follow a ballistic flight path to the canopy. Their sedimentation is driven by gravity as long as air movement does not transport them horizontally or vertically. Moving air means that fine droplets require much more time for sedimentation and this occurs over a comparably wide range. Even very calm conditions result in a transition zone of about 1 m in case the drift potential in terms of the fine drop volume is big enough. The number of particles and the volume of spray fluid which are exposed to the drift process are the factors causing deposition on plant surfaces to be ecotoxicologically relevant or not. Consequently, reduction of drift primarily depends on the fine drop volume of the application technique (Koch et al. 2003).

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