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Agriculture, Ecosystems and Environment 111 (2005) 340–348
Agriculture Ecosystems & Environment
www.elsevier.com/locate/agee

Pesticide interception by emergent aquatic macrophytes: Potential to mitigate spray-drift input in agricultural streams

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Received 9 February 2005; received in revised form 15 June 2005; accepted 17 June 2005
Available online 26 August 2005

Abstract

An increasing amount of research has focused on alternate methods to mitigate pesticide exposure in agricultural surface waters. The interception of spray-drift-derived azinphos-methyl (AZP) by emergent aquatic macrophytes was investigated in a tributary of the Lourens River, South Africa. The stream was dominated (80% coverage) by three species of emergent aquatic macrophytes; *Juncus capensis*, *Fuirena hirsuta* and *Pycreus* sp. During an application of AZP, drift deposition was determined on the surface of the vegetation, on the surface of the exposed channel of the stream and beneath *J. capensis* and *F. hirsuta* by means of drift collectors ($n = 6$). Drift deposition on the surface of the vegetation (1.5 ± 0.3 mg/m^2) was well predicted by 90th percentile basic drift values (1.3 mg/m^2), indicating that the sampling devices resulted in an accurate measurement of drift deposition. Drift deposition on the surface of the exposed channel (1.0 ± 0.3 mg/m^2) was lower than measured on the vegetation surface indicating a positive shielding effect by the emergent plants. Drift deposition beneath *J. capensis* was significantly lower ($p = 0.005$) than on the vegetation surface and the exposed channel ($p = 0.048$), indicating highly effective interception of AZP. A simple formula was generated to make predictions of drift deposition reductions based on different percentage macrophyte coverage. Predictions showed that 50% macrophyte coverage in combination with a 5 m buffer strip resulted in as large a reduction in drift deposition as the combination of a 10 m buffer strip with 0% macrophyte coverage. Results thus indicate that emergent aquatic vegetation may be as effective a mitigation strategy for reducing spray-drift induced pesticide input as increasing the width of the no spraying buffer zone.

Keywords: Spray-drift; Emergent aquatic macropyhte; Interception; Mitigation; Stream

1. Introduction

Spray-drift is one of the most important sources of nonpoint-source pesticide pollution in edge-of-field surface waters, such as ditches, streams and ponds (Groenendijk et al., 1994). Pesticide concentrations associated with spray-drift are often high due to the

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doi:10.1016/j.agee.2005.06.004

direct input of pesticides (Gilbert and Bell, 1988; AEDG, 1992) and thus pose significant risk for aquatic fauna. Amidst heightened awareness for sustainable development and increasingly stringent regulatory measures, increased emphasis has been placed on mitigatory measures in an attempt to reduce nonpoint-source pesticide pollution in agricultural surface waters (Streloke and Brown, 2003). In particular, higher-tier risk assessments play an important role in characterizing the impact of mitigatory measures on the fate and toxicity of pesticides in surface waters (Mackay et al., 2002).

With respect to spray-drift, higher tier risk assessments have focused on the potential of submerged aquatic macrophytes in reducing drift-related pesticide exposure in surface waters. Aquatic macrophytes in ditches and wetlands have been shown to be effective in reducing concentrations of water-dissolved pesticides resulting from spray-drift (Brock et al., 1992; Schulz et al., 2003). Macrophytes provide large surface areas for adsorption of water-dissolved pesticides (Hand et al., 2001), a factor which has recently been incorporated into fate models such as TOXSWA (Adriaanse, 1997).

Foliar interception of pesticides by sprayed crops results in a decrease in deposition rate on the soil surface, the extent of which is dependent on factors such as the growth stage and physical characteristics of the crop. Interception factors for different crop types have been established and are currently used in EU and US risk assessment procedures (Pfleeger et al., 1996; Linders et al., 2000). Many aquatic macrophyte species found in agricultural ditches are emergent (e.g. *Juncus* sp., *Typha* sp.), with their leaves protruding above the water surface. In addition to adsorbing water-dissolved pesticide concentrations, emergent macrophytes may thus provide a mitigatory function in reducing spray-drift-related pesticide input in surface waters through foliar interception of spray droplets before they land on the water surface. This feature has been alluded to in a previous study (Schulz et al., 2001), although no detailed study has investigated this potentially efficient mitigatory factor.

Azinphos-methyl (AZP) is commonly applied to forelle pear (*Pyrus communis* L.) orchards at approximately one application every 2 weeks from October to January (Dabrowski and Schulz, 2003) in the Lourens River catchment in the Western Cape of South Africa. Numerous studies performed in the catchment have shown that the pesticide enters tributaries as a result of spray-drift (Schulz et al., 2001; Dabrowski and Schulz, 2003) at concentrations capable of eliciting ecotoxicological community responses (Schulz et al., 2002). Most of the tributaries of the river are essentially man-made drainage ditches, many of which are intensively vegetated with emergent aquatic macrophytes.

The main aim of this study was to determine the potential of emergent aquatic macrophytes in reducing spray-drift-related AZP deposition in a heavily vegetated tributary bordering an intensively sprayed pear orchard. Measured AZP deposition rates were compared to predicted rates that were made using basic 90th percentile drift values (Rautmann et al., 2001). Results were used to develop a basic predictive formula that was used to forecast deposition rates based on different macrophyte coverage percentages.

2. Materials and methods

2.1. Study site

The study took place in the Kleinvlei tributary of the Lourens River, which has a catchment area of 92 km^2 of which 400 ha are cultivated under fruit

Table 1
Coverage and species composition of emergent aquatic macrophytes (±standard error; $n = 20$) in a 200 m stretch of tributary of the Lourens River, South Africa

	Width (m)	Area (m^2)	Area (%)	Species composition (%)		
				Juncus capensis	*Fuirena hirsuta*	*Pycreus* sp.
Unvegetated channel	0.56 (±0.04)	101	21.8	0	0	0
Vegetated left zone	1.15 (±0.12)	208	42.7	56 (±8.2)	36.2 (±9.8)	7.8 (±9.8)
Vegetated right zone	0.98 (±0.07)	178	36.5	37.4 (±6.9)	41.8 (±8.9)	20.9 (±6)
Total vegetated coverage	–	386	79.2	37.5	31.1	11.3

Table 2
Physical characteristics (±standard error; $n = 15$) of three emergent macrophyte species in a vegetated tributary of the Lourens River, South Africa

Species	Density (ramets/m^2)	Leaf area (cm^2)	Height (cm)
Juncus capensis	125	12.1 (±2.4)	18.1 (±1.2)
Fuirena hirsute	170	6.3 (±1.5)	23.6 (±3.3)
Pycreus sp.	151	5.7 (±2.0)	21.4 (±4.1)

orchards and vineyards. The tributary is separated from an adjacent pear orchard by a 5–15 m buffer zone and is dominated by dense emergent aquatic vegetation, which covers almost 80% of the surface area of the stream (Table 1). The vegetation grows to form a distinct, narrow, unvegetated central channel, flanked on either side by dense, wide marginal aquatic emergent vegetation zones that grow from within the water body (left and right vegetated zone). The macropyhte community comprises three species, *Juncus capensis*, *Fuirena hirsuta* and *Pycreus* sp., of which *J. capensis* and *F. hirsuta* are the most dominant (Table 1). Both species occur throughout the Western Cape and are common in damp lowland systems (Goldblatt and Manning, 2000). *F. hirsuta* and *Pycreus* sp. have narrow, needle-like pubescent leaves and stems, while *J. capensis* has a comparatively broader filiform leaf shape (Table 2).

2.2. Experimental design

Drift deposition was measured in the tributary during an application of AZP to the adjacent pear orchards on 13 November 2002. AZP was applied to the orchards by Jacto Airbus (Sao Paulo, Brazil) air-assisted mist blowers, which delivered AZP at a rate of 0.15 kg a.i./ha in 1000 L of water at a pressure of approximately 1200 kPa. The distance of the tributary from the edge of the treated area was 5 m. Spray deposition was measured by drift collectors that consisted of acetone- and distilled-water-rinsed flat straight-sided glass Petri-dishes (diameter: 15 cm; surface area: 0.02 m^2) containing distilled water. Drift deposition rates were measured in four treatment areas (Fig. 1): the surface of the vegetation canopy (S), where deposition was expected to be 100%; in the mid-stream on the surface of the nonvegetated channel (M) so as to measure any possible shielding effect caused by adjacent emergent vegetation; and beneath the coverage of *J. capensis* (J.c) and *F. hirsuta* (F.h) so as to determine the degree of interception by the two plant species. No deposition rates were measured beneath *Pycreus* sp., as it was far less abundant than the other two species and therefore did not occur in each sampling zone (Table 2). Wooden beams laid across the stream supported dishes collecting drift deposition in the channel. Dishes placed beneath emergent vegetation (F.h and J.c) were placed on the water surface and were small enough so as not to disturb the density and structure of the vegetation above the dishes. Surface vegetation (S) collectors were placed on top of the vegetation and the dense aggregation of the plants prevented the dish from falling through the canopy. Three sampling zones (SZ1–SZ3, each 10 m long) were selected along the stretch of the stream (Fig. 2). Each zone accommodated two driving rows (gaps in between orchard rows along which the spraying tractors moved) along which pesticide was applied to adjacent tree rows. All four treatments (S, M, F.h and J.c) were sampled twice within each zone such that mid-stream samples were taken at six sites along the centre of the stream in the exposed channel, and surface vegetation samples and samples beneath the two vegetation types were collected at three sites in the right and left zone respectively. Thus in total six replicate samples were collected for each treatment. As the orchard tree rows

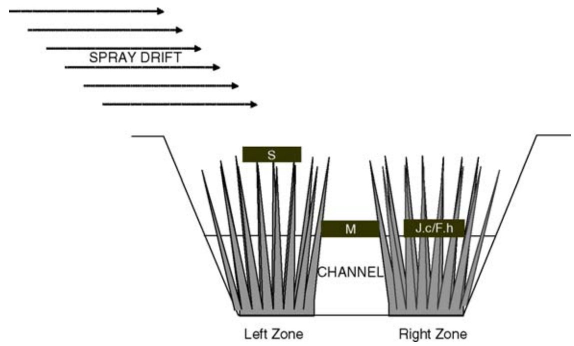

Fig. 1. Diagram (not to scale) of the placement of the drift collectors (black bars) deployed for the measurement of deposition of azinphos-methyl (AZP) in a vegetated tributary of the Lourens River, South Africa. At each sampling point deposition of AZP was measured on the surface of the vegetation canopy (S), on the surface of the unvegetated channel (M) and at the base of two emergent aquatic macrophyte species; *Juncus capensis* (J.c) and *Fuirena hirsuta* (F.h).

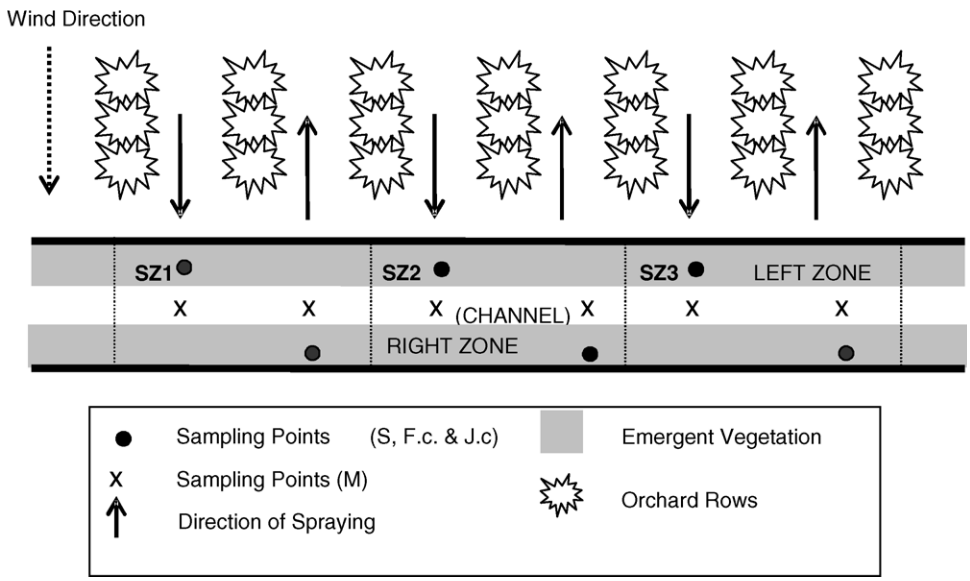

Fig. 2. Diagram (not to scale) of the position of sampling points ones (SZ1, SZ2 and SZ3) for measurement of deposition of azinphos-methyl on the surface of the emergent vegetation canopy (S) at the base of two emergent aquatic macrophytes, *Juncus capensis* (J.c) and *Fuirena hirsuta* (F.h) and on the surface of the unvegetated channel (M).

were orientated perpendicular to the tributary a well-defined cloud of spray-drift moved from the orchard in the direction of the tributary. Prior to the start of the application collectors were placed in SZ1. After spraying was completed in the two rows within SZ1, the collectors were immediately removed and new collectors were then placed in SZ2. The same procedure was repeated for SZ3. The purpose of this was to prevent cross contamination of collectors between the zones so that each collector represents one single deposition event. Once the collectors were removed from the stream, the water was immediately poured from the dishes into acetone- and distilled water-rinsed glass jars and kept on ice until solid phase extraction was carried out.

2.3. Pesticide analysis

Samples were solid-phase extracted within 5 h after sampling using Chromabond® C18 columns (Macherey-Nagel, Düren, Germany). The columns were air-dried for 30 min and kept at −18 °C until analysis. Analysis was performed according to methods described in Dabrowski et al. (2002). Measurements were done using gas chromatography (HP 5890) fitted with standard HP electron-capture, nitrogen-phosphorus, and flame-photometric detectors. Identity of AZP was confirmed by matching retention times on three different stationary phases. Method validation employed water matrices that were found to have no detectable levels of the investigated pesticides. The matrices were spiked at eight spiking levels over the range of concentrations found in the actual samples. Overall mean recoveries were between 79 and 106%. For quality control, a matrix blank was analysed with each extraction set. The investigated pesticides were never detected in matrix blanks. The detection limits were 0.01 μg/L.

2.4. Data analysis

Based on concentrations measured in the drift collectors the deposition rate in each treatment (mg/m^2) was ascertained. Significant differences between treatments were tested by means of a one-way ANOVA and a Fischer's PSLD post hoc test. Measured deposition rates were compared to predicted rates in order to validate the sampling technique. Deposition rates in the stream were predicted using basic 90th percentile drift values (Rautmann et al., 2001) using a value of 8.41% of applied pesticide landing on the stream surface (based on a 5 m buffer zone in between the orchards and the tributary). Thus, based on an application rate of 0.15 kg a.i/ha (or 0.015 g/m^2), predicted deposition rates on the stream surface were calculated to be 6.75×10^{-4} m^{-2}. Using the surface area of the dish, the total expected load of azinphos-methyl landing in the dish was estimated and compared to measured loads.

3. Results and discussion

3.1. Interception

Predicted deposition rates (1.3 mg/m^2) compared well with average measured deposition rates (1.5 ± 0.5 mg/m^2; $n = 6$) on the vegetation surface. The basic drift values (Rautmann et al., 2001) used for predicting values in the stream are widely used in aquatic pesticide exposure assessments for surface waters (FOCUS, 2001) and have been shown to be valid in previous studies in the Lourens River catchment (Schulz et al., 2001; Dabrowski and Schulz, 2003). The high standard error may have resulted from the fact that three drift samplers received drift when the spray rig was approaching the stream, whilst the other three drift samplers received drift whilst the rig was leaving the stream (Fig. 2). Pesticide deposition was highest in the surface vegetation drift collectors, with lower rates being measured on the surface of the unvegetated channel (Fig. 3).

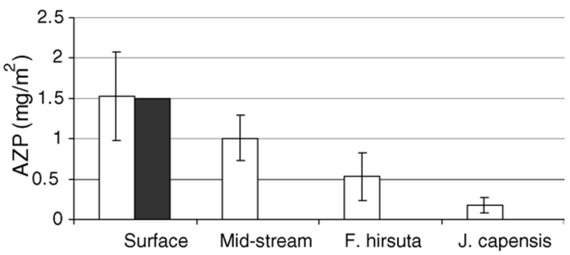

Fig. 3. Graph showing the measured deposition of azinphos-methyl (AZP; white bars; ±standard error; $n = 6$) on the of the canopy surface of marginal emergent vegetation (surface), on the surface of the unvegetated channel (mid-stream) and at the base of two species of emergent aquatic macrophytes; F.h (*Fuirena hirsuta*) and J.c (*Juncus capensis*); in a vegetated tributary of the Lourens River, South Africa. The black bar represents the predicted deposition on the surface of the canopy of marginal emergent vegetation.

The fact that the basic drift values accurately predicted measured deposition values indicates that the sampling method utilized in the study was appropriate. Furthermore, the 33.6% reduction of spray deposition measured on the surface of the exposed channel is lower than normally would be expected. It would thus appear that the emergent vegetation shields the channel to a degree and intercepts drift particles before they land on the channel surface. The fact that vegetation restricts the channel to a narrow width presumably facilitates this reduction. Reduction in macrophyte coverage and the resulting increase in channel width would thus potentially reduce this shielding effect. Vegetation in buffer zones (Hall et al., 1996) and edge-of-field vegetative wind-breaks (Ucar and Hall, 2001) and hedgerows (Longley and Sotherton, 1997; Longley et al., 1997) have been shown to be highly effective in intercepting drift from orchards to adjacent water bodies, although the present study is the first that has demonstrated the potential of in-stream marginal emergent aquatic vegetation in reducing pesticide deposition on the nonvegetated water surface. Morphological characteristics of the plants would presumably influence the shielding effect to a large degree. In particular, vegetation height would play an important role by reducing the angle of incidence of the exposed channel to the direction of the on-coming drift. Wind direction and speed would also influence the amount of drift the channel is exposed to (Davis et al., 1991; Longley and Sotherton, 1997) and therefore the amount that ultimately lands up on the channel surface. The influence of wind factors on the potential of emergent aquatic plants to intercept pesticide inputs in surface waters warrants further investigation.

The positive effect of the vegetation on pesticide drift reduction is further apparent when comparing deposition rates beneath the two vegetation types to expected and measured values on the vegetation surface. Respective deposition rates measured beneath *J. capensis* and *F. hirsuta* were 88% (significant reduction; $p = 0.005$; $n = 6$) and 65% (not significant) lower than those measured on the surface of the vegetation. Deposition rates measured below *J. capensis* were also significantly lower than those measured in the mid-stream channel ($p = 0.048$; $n = 6$); rates beneath *F. hirsuta* were lower but not significant (Fig. 3).

Two studies performed on alfalfa have shown that the plants intercept applications of AZP and thus reduce pesticide concentrations on the soil surface by up to 84% (Bennett et al., 1994; Schauber et al., 1995). Values of interception factors for emergent aquatic macrophytes have not been reported in the literature. Interception factors have however been studied in greater detail for agricultural crops, and recently a proposal for determining interception factors based on the growth phase or leaf area index of the crop has been derived (Linders et al., 2000). Interception factors reported in this study are within the upper range of these values. Additional variables influencing interception factors include the surface area of the leaves (Pfleeger et al., 1996), vegetation height (Schauber et al., 1995), canopy structure and plant densities (Linders et al., 2000). The highly efficient interception by *J. capensis* is most likely as a result of the broad leaf shape occurring in high densities which presents a larger surface area than leaves of *F. hirsuta*, which are in the form of long thin spikes (Table 2). The high degree of variance in treatments could be explained by the variation in distance of drift collectors from the point of application. Collectors placed in the left vegetated zone were up to 1 m further away from those in the right zone and generally received less drift, although no statistical differences were apparent. Previous studies measuring interception of AZP also found a high degree of variance which was attributed to the distance of treatment plots from the spraying boom (Bennett et al., 1994). Although not studied in detail, the leaves of *J. capensis* were orientated relatively uniformly (upright position), whilst those of *F. hirsuta* were orientated at a variety of angles, which may also account for the high degree of variance of percentage interception by this species (Koch and Weisser, 2001).

The half-life of AZP on plant surfaces is reported to be from 1.7 to 5.1 days (Bennett et al., 1994) and thus degrades fairly rapidly after interception. Interception data from this present study and half-life data thus indicate that emergent aquatic macrophytes are highly effective in reducing spray-drift-related AZP loads to the water column of the stream. Aquatic macrophytes are often removed from agricultural ditches to promote rapid drainage from fields during heavy rainfall events (Beltman, 1984). The benefit of submerged sections of aquatic macrophytes in improving water quality via assimilation and adsorption of pollutants has however been well documented (Meulemann et al., 1990; Schulz et al., 2003).

The findings of this present study provide additional support for the overall positive effect of aquatic macrophytes in reducing nonpoint-source pesticide input. Most importantly, aquatic macrophytes need to be effectively managed in agricultural surface waters so as to realize to their full benefits in improving water quality. The Lourens River has a high conservation status (Tharme et al., 1997) and effective management of the catchment is required to minimize potential pesticide-related risks. As the tributaries serve as the main source of pesticide contamination in the mainstream (Dabrowski et al., 2002), aquatic macrophytes can have a significant impact in reducing drift deposition in the tributaries. Furthermore, as pesticide application takes place during the hot, dry summer months the risk of intercepted pesticides entering the water body via rainfall is relatively low. Thus, in the context of the Lourens River, clearing of vegetation could took place in winter and thus facilitate rapid drainage of fields, without compromising the benefits that the macrophytes provide in terms of interception and adsorption of spray-drift-derived pesticide concentrations during the summer spraying season.

3.2. Extrapolated predictions

Based on the 33.6% reduction of spray-drift deposition in the unvegetated channel as a result of the shielding effect of the adjacent vegetation, a negative exponential relationship could be derived between drift reduction in the unvegetated area of the stream and the percentage of exposed area. This relationship assumes 75% drift reduction when 0% of the channel is unvegetated (based on the mean of the reduction for *J. capensis* and *F. hirusta*) and 0% drift reduction when 100% of the stream is unvegetated (based on the expected deposition derived from 90th percentile basic drift values).

The resulting equation can thus be used to calculate the reduction of spray deposition in the nonvegetated channel based on the percentage nonvegetated channel area of the stream. The model thus assumes that the unvegetated area of the stream will always be confined to the centre of the stream and will be flanked on either side by the emergent aquatic vegetation. Based on this model an interception factor of 0.65 and 0.88 for *F. hirsuta* and *J. capensis* respectively, and percentage coverage of each plant type with respect to the total area of the stream, a predictive formula was generated:

$$\text{Total load(mg)} = \text{SA} \times \text{ED}(f(\text{M}) + 0.65(\text{F.h}) + 0.88(\text{J.c}) + 0.65(\text{Pyc}))$$

where SA is the total surface area of stream adjacent to an orchard (m^2); ED the expected deposition (mg/m^2) based on basic 90th percentile drift values (Rautmann et al., 2001); $f = 77.215\ e^{-0.0434M}$ (variable describing the exponential relationship between nonvegetated channel area and the shielding effect of adjacent emergent vegetation, where M the % nonvegetated channel area); F.h the % area covered by *F. hirsuta*; J.c the % area covered by *J. capensis*; Pyc the % area covered by *Pycreus* sp. (an interception factor of 0.65 was assumed as the plant was similar in morphological characteristics to *F. hirsuta* (Table 2)).

Using the formula, predictions were generated for different total percentages of area of vegetation coverage in order to estimate total drift reductions with respect to application of AZP at 5, 10 and 15 m distance from the stream. The proportion of area covered by each of the three plant species was assumed to be the same for each prediction (37.5% *J. capensis*; 31.1% *F. hirsuta*; 11.3% *Pycreus* sp.).

Predicted drift deposition reductions were calculated relative to expected deposition with a buffer strip of 5 m (as in the case of the studied stream) with no vegetative coverage. Predicted drift reductions provide additional support for the efficiency of emergent aquatic vegetation in reducing drift-related pesticide loads in water bodies, with 67% of drift deposition being potentially reduced along the entire stretch of the stream at 80% macrophyte coverage (Table 3). Thus the high interception factors of the two plant species in combination with the fact that the extensive macrophyte coverage reduces the area of the exposed nonvegetated channel to such a degree, results in a large reduction in drift deposition of AZP along the entire stretch of the stream.

Interception factors for different crop types are incorporated into models (e.g. PRZM) used in regulatory exposure assessments in order to estimate the amount of applied pesticide that reaches the soil and is thus available for processes such as leaching and surface runoff (Linders et al., 2000). In the USA, the Kenaga nomogram is used in terrestrial exposure assessments according to the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and can be used to calculate plant interception factors based on the structure of the plant and the application rate of the applied pesticide (Pfleeger et al., 1996). The existence of these models coupled with the results of the study therefore present a strong argument for the development of interception factors related to emergent aquatic vegetation, which could then be incorporated into fate models. Existing fate models designed to estimate predicted environmental concentrations (PECs) in surface waters as a result of drift deposition (e.g. TOXSWA) do not incorporate the effect of interception by emergent aquatic plants (Adriaanse, 1997) and could thus over-estimate PECs in ditches where emergent macrophytes are present. Further development of the model and interception factors would rely on trials investigating the potential of different emergent aquatic plant species in reducing drift deposition based on characteristics such as density, height, surface area and orientation of emergent leaves.

Table 3
Prediction of spray-drift-derived loads of azinphos-methyl (AZP) in a vegetated tributary of the Lourens River, South Africa, based on different percentage area coverages of emergent macrophytes and buffer zone distances of 5, 10 and 15 m

	Vegetation coverage			
	0%	25%	50%	80%
mg AZP (5 m)	740.8	539.8	382.7	242.1
% reduction	0	27.1	48.3	67.3
mg AZP (10 m)	326.8	182.5	148.1	106.8
% reduction	44.1	75.4	80.0	85.6
mg AZP (15 m)	136.6	76.3	61.9	44.6
% reduction	81.6	89.7	91.7	94.0

3.3. Mitigation strategies

Increasing the width of the buffer zone has been proposed as one of the most effective mitigation strategies for reducing drift of pesticides from the edge-of-field to adjacent water bodies (De Snoo and De Wit, 1998). This option may often not be agronomically feasible, as it means that a large surface area is lost to farmers for production of crops (Hewitt, 2000). In the present study, in the absence of macrophyte coverage an increase in buffer zone width from 5 to 10 m results in a 44% reduction in spray deposition which is comparable to reductions with 50% in-stream vegetation coverage and lower than 80% coverage in combination with a buffer zone width of 5 m. The results thus indicate that emergent macrophytes may be as effective as increasing buffer zone width in terms of reducing drift deposition in aquatic water bodies and may therefore be considered as a highly effective and viable risk mitigation strategy. It is also clear that overall positive effect of the emergent vegetation in terms of percentage reduction of drift deposition reduces with increasing buffer strip distance. In the case of a 5 m buffer strip, 80% coverage results in a 67.3% increase in reduction of drift deposition in comparison to 0% coverage. In the case of a 10 and 15 m buffer strip, reduction is only increased by 41.5 and 12.4% respectively. Thus, in terms of a management scenario, the possibility for compromise exists between maintaining a dense coverage of emergent aquatic vegetation adjacent to fields with narrow buffer strips (<5 m), or by establishing a wide buffer strip, with relatively little emergent coverage in an adjacent stream or ditch. It is essential however, to establish the potential ecological consequences of pesticide adsorbed on plant surfaces on terrestrial species (e.g., birds and insects) that may utilize the vegetation for habitat or nesting, before interception can be recommended as a viable mitigation strategy.

Risk mitigation is a relatively new field and is coming under ever increasing scrutiny, particularly with respect to pesticide registration. Different mitigatory strategies are generally poorly understood (FOCUS, 2001) which has resulted in the formation of bodies such as the FOCUS group on Landscape and Mitigation Factors in Ecological Risk Assessment, which aim to harmonize and develop mitigation options (Streloke and Brown, 2003). In this respect the results of the present paper provide additional insight into the role of aquatic macrophytes in effective pesticide risk mitigation and suggest that the effective management of aquatic macrophytes in agricultural ditches may be one of the most important mitigation options with respect to spray-drift-derived pesticide input into agricultural surface waters.

4. Conclusion

Interception of spray-drift by emergent aquatic vegetation is potentially a highly efficient mitigation tool, with pesticide deposition being reduced by up to 67% in the studied stream. Predictive modelling using 90th percentile drift values indicates that emergent aquatic vegetation may be as effective in reducing spray deposition in surface waters as increasing buffer zone width. The potential ecological consequences of pesticide deposition on plant surfaces needs to be considered however, before interception by emergent aquatic macrophytes can be regarded as a viable mitigation strategy.

Acknowledgements

This study is part of the ENVIROMAP (http://www.tu-bs.de/enviromap) project, which is a German-South African collaborative project, funded by the Volkswagen Stiftung, Hannover (Project: I/76 177). The authors thank Jenny A. Day for financial assistance, Sue K.C. Peall and Christina Hahn for sample preparation and analysis and the farmers for permission to enter their properties and for information on spraying programmes.

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