DOES INSECTICIDE DRIFT ADVERSELY AFFECT GRASSHOPPERS (ORTHOPTERA: SALTATORIA) IN FIELD MARGINS? A CASE STUDY COMBINING LABORATORY ACUTE TOXICITY TESTING WITH FIELD MONITORING DATA

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Abstract—The current terrestrial risk assessment of insecticides regarding nontarget arthropods considers exclusively beneficial organisms, whereas herbivorous insects, such as grasshoppers, are ignored. However, grasshoppers living in field margins or meadows adjacent to crops may potentially be exposed to insecticides due to contact with or ingestion of contaminated food. Therefore, the present study assessed effects of five active ingredients of insecticides (dimethoate, pirimicarb, imidacloprid, lambda-cyhalothrin, and deltamethrin) on the survival of *Chorthippus* sp. grasshopper nymphs by considering two routes of exposure (contact and oral). The experiments were accompanied by monitoring field margins that neighbored cereals, vineyards, and orchards. Grasslands were used as reference sites. The laboratory toxicity tests revealed a sensitivity of grasshoppers with regard to the insecticides tested in the present study similar to that of the standard test species used in arthropod risk assessments. In the field monitoring program, increasing grasshopper densities were detected with increasing field margin width next to cereals and vineyards, but densities remained low over the whole range of field margins from 0.5 to 20 m next to orchards. Grasshopper densities equivalent to those of grassland sites were only observed in field margins exceeding 9 m in width, except for field margins next to orchards. These results may indicate that current insecticide risk assessments are insufficiently protective for grasshoppers in field margins. Environ. Toxicol. Chem. 2012;31:1874–1879. © 2012 SETAC

Keywords—Risk assessment   Herbivorous arthropods   Oral exposure   Insecticides   Nontarget arthropods

INTRODUCTION

Biodiversity has been adversely affected by intensified agricultural activities during the last decades [1,2], with drift of pesticides into nontarget areas [3] such as field margins identified as a driving factor for the observed biodiversity decline in agricultural landscapes [4,5]. The biodiversity decline is not only observed in birds and plants but also in many arthropod taxa such as moths, butterflies, carabids, and wild bees [5–7].

Current terrestrial risk assessments for insecticides only consider a small set of nontarget arthropod species, primarily beneficial organisms [8], with a focus on an aphid parasitoid wasp (*Aphidius rhopalosiphi*) and a predatory mite (*Typhlodromus pyri*). Furthermore, only the contact exposure scenario (glass-plate tests) is assessed, which in turn excludes any risk of exposure via food ingestion by herbivorous arthropods. Food ingestion of herbivorous insects, however, is high because of the low nutritious value of the vegetation, compared with predatory arthropods that feed on a diet rich in proteins [9]. Therefore, oral exposure to insecticide residues on the vegetation is presumably higher in herbivorous insects compared with the standard beneficial arthropods.

Moreover, many herbivorous arthropods such as grasshoppers are of particular concern because they inhabit field margins (e.g., for reproduction; see Laußmann [10] and Maas et al. [11]). Hence, grasshoppers may be exposed to insecticides due to surface contact and/or ingestion of plant material containing insecticide residues [12]. Moreover, grasshoppers are of ecological importance within the terrestrial food web because many species of birds, small mammals, amphibians, reptiles, and

spiders include grasshoppers in their diet [13]. Some grasshopper consumers are even highly specialized, such as Swainson's hawk (*Buteo swainsoni*); grasshopper control with monocrotophos in the pampas of Argentina led to high mortality in these hawks because of contaminated food [14].

Although a significant role of insecticide drift in the decline of nontarget Orthopteran species can be anticipated [11,13], we are aware of only one study that has investigated the effects of insecticides on grasshoppers [12]. Due to the drift of insecticide application with Karate (field rate of 7.5 active ingredient [a.i.] g/ha lambda-cyhalothrin), a reduction in grasshopper density within a 6- to 8-m-wide field margin after an application in June 2000 was observed, followed by recovery after 14 d [12]. Studies assessing the implications of different exposure scenarios, namely, surface contact, oral contact, and a combination of both, are not found in the scientific literature. The present study investigates effects of five commonly used insecticides, namely, Rogor (400 a.i. g/ha dimethoate; Spiess Urania), Pirimor (500 a.i. g/ha pirimicarb; Syngenta), Confidor (100 a.i. g/ha imidacloprid; BayerCropScience), Karate (100 a.i. g/ha lambda-cyhalothrin; Syngenta), and Decis (25 a.i. g/ha deltamethrin; BayerCropScience) [15], on the survival of first instar *Chorthippus* sp. nymphs by considering different routes of exposure (contact, oral, and both contact and oral exposure). Additionally, grasshopper density in field margins of various widths located next to cereals, vineyards, and orchards was assessed in a monitoring phase between June and August 2008.

MATERIALS AND METHODS

Laboratory studies

Insecticides. The insecticides investigated in the present study, which exhibit different modes of action, were applied as commercially available formulations (Table 1).

Table 1. Product name, producer, a.i., chemical class, mode of action, and recommended application rate for cereals of the commercially available insecticides assessed

Product	Producer	a.i. (content)	Chemical class	Mode of action	Application rate (g a.i./ha)
Rogor	Spiess Urania	Dimethoate (400 g/L)	Phosphodithioic acid	AChE inhibitor	600
Pirimor	Syngenta	Pirimicarb (500 g/kg)	Carbamate	AChE inhibitor	150
Confidor	BayerCropScience	Imidacloprid (700 g/kg)	Neonicotinoid	Inhibition of $Na+$ channel	112
Karate	Syngenta	Lambda-cyhalothrin (100 g/L)	Pyrethroid	Inhibition of $Na+$ channel	7.5
Decis	BayerCropScience	Deltamethrin (25 g/L)	Pyrethroid	Inhibition of $Na+$ channel	7.5

a.i. = active ingredient; AChE = acethylcholinesterase.

The formulations, rather than the pure active ingredients, were used because insecticides are applied as formulations and thus enter the nontarget area together with their additives. Each insecticide was diluted in distilled water to achieve five nominal concentrations. The recommended field application rate (Table 1) for cereals of each insecticide was used as reference point for the highest test concentration (100%), whereas the other nominal test concentrations corresponded to 33.33, 11.11, 3.70, and 1.20% of the recommended field application rate.

Test organisms and grass mixtures. Juvenile grasshoppers can potentially be exposed to the drift of insecticides, because the eclosion period (May–June) of many grasshopper species [16] corresponds to the main insecticide application period [17]. In the present study, first instar nymphs of the meadow grasshopper *Chorthippus parallelus*, which also inhabits field margins, were used [11]. *Chorthippus parallelus* was sampled from grassland near Landau, Germany (49°13′N, 8°2′E), where it co-occurred with *Chorthippus dorsatus*. Because both species cannot be morphologically separated from each other during the first instar [18], a mixture of both species may have been assessed during the toxicity tests. Hence, the test grasshoppers are referred to *Chorthippus* sp. throughout the present study.

Chorthippus sp. were sampled between May and June 2009 with a sweep net. The first instar nymphs were separated by using an exhaustor (11 × 4 cm; Bioform) directly on the grassland and transported in mini-life-tubes (0.36 × 0.83 cm; Bioform) to the laboratory. In the laboratory all individuals were kept together for at least 12 h under a natural light/dark rhythm in a terrarium covered with a mesh screen (white double yarn, 1-mm mesh size; Windhager) for continuous aeration. This procedure facilitated identifying and finally excluding injured individuals. Additionally, a complete mixing of sampled grasshoppers was ensured, which minimized the probability of allocating only juveniles released from a single clutch in one replicate [13,16]. The terrarium bottom was covered by a 1-cm quartz sand layer, and a water-drenched wad of cotton wool served as a watering place. As food, a mixture of four grass species was offered ad libitum (*Arrhenatherum elatius*, *Dactylis glomerata*, *Lolium perenne*, and *Festuca guestfalica*) and wheat (*Triticum* L.), which is preferred by *Chorthippus* sp. [11]. The grass and wheat mixture (=grass mixture) was grown in multi-pot plates from seeds (ordered from Rieger-Hofmann) under natural conditions in commercially available fertilized potting soil and watered if necessary. Each pot with the grass mixture had a base area of 4 cm^2 soil; when the blades of grass had reached approximately 10 cm in height, the pot was placed into the terrarium or test vessel.

Spraying procedure and toxicity test. A purpose-built, air-assisted experimental sprayer (Schachtner Gerätetechnik) equipped with four 110° flat-fan "TeeJet" nozzles (XR 11002-VS; Schachtner Gerätetechnik) was used to spray the respective insecticide concentration onto the surface of the test vessels (plastic boxes of 6 cm height and 121 cm^2 base area covered with a mesh screen for continuous aeration; Bellaplast) or the pots with the grass mixtures (described above). The nozzles were integrated in a fume cupboard (with a distance of 0.25 m between the nozzles and at a height of 0.7 m above the application area), calibrated to meet the recommended application rate of arable crops of 400 L/ha [19] and cover the surface of the vessels and grass mixtures with a homogeneous spray deposit. For calibration, test vessels were sprayed with distilled water and then weighed to ensure the desired application rate. Only after the calibration was confirmed three times in a row was insecticide application started. After spraying, vessels and grass mixtures were left until dry. Subsequently, five randomly selected *Chorthippus* sp. nymphs were transferred with an exhaustor from the terrarium to the test vessels, after being narcotized with carbon dioxide gas.

Three treatments, each with six concentrations including control, were performed. In the first treatment group, grasshopper nymphs were exposed via contact only to the contaminated plastic surface of the test vessels (contact exposure), which is in accordance with the laboratory test for *A. rhopalosiphi* [20]. In the second treatment group, nymphs were exposed only to oversprayed grass mixtures (oral exposure). In the third treatment group, both exposure pathways were combined (contact and oral exposure); both the grass mixture and the surface area were contaminated with the respective insecticide concentration. All replicates were equipped with a water-drenched wad of cotton wool, which served as a water source. Approximately 8 h after the introduction of the test organisms into the respective test vessels, those replicates belonging to the surface-exposure scenario received a noncontaminated grass mixture.

All test vessels were kept outdoors under semifield conditions, protected from rainfall and direct sun at a mean temperature of 21.0°C (± 5.2 SD) and mean relative humidity of 62.6% (± 24.0 SD). Effects on the test organisms were recorded after 48 h and categorized as "alive" without any observable effects or with constrained movements and "lethal." This procedure was used to assess the toxicity of five insecticides (Table 1). For each insecticide, five concentrations with six replicates each were set up, whereas the control treatment (distilled water) was replicated 10 times.

Field monitoring

Grasshopper populations were recorded at 110 sampling sites in field margins located next to cereal fields, vineyards, orchards, and in grasslands around Landau (South Rhineland Palatinate, Germany) from June to August 2008. The distances between sampling sites were at least 100 m. Field margins were defined as unused, elongate, and predominantly grassy nontarget areas, exhibiting a minimal width of 0.5 m and placed between two cropped areas or between one cropped area and a road. Grasslands and meadows used to determine the possible

Table 2. Number of replicates (*n*), mean vegetation height, and cover (±SD) for grassland and each field margin width class neighboring cereals, vineyards, and orchards

Sampling site	Width class	*n*	Vegetation height (cm)	Vegetation cover (%)
Grassland		10	19.0 ± 14.0	81.0 ± 12.0
Cereals	>0.5 to 3 m	11	20.9 ± 8.1	87.1 ± 13.9
	>3 to 6 m	16	18.5 ± 4.2	82.0 ± 9.5
	>6 to 9 m	3	25.4 ± 2.3	75.7 ± 15.1
	>9 to 20 m	4	14.1 ± 2.7	90.3 ± 8.3
Vineyards	>0.5 to 3 m	17	14.1 ± 7.5	84.8 ± 9.5
	>3 to 6 m	11	13.9 ± 5.5	82.6 ± 8.2
	>6 to 9 m	9	17.5 ± 7.5	89.1 ± 7.8
	>9 to 20 m	9	17.3 ± 3.7	89.8 ± 7.1
Orchards	>0.5 to 3 m	8	13.6 ± 5.9	81.1 ± 12.2
	>3 to 6 m	6	15.1 ± 4.2	85.3 ± 8.0
	>6 to 9 m	3	10.3 ± 2.8	87.5 ± 10.8
	>9 to 20 m	3	15.5 ± 3.3	93.7 ± 4.9

maximum population capacity were located within the agricultural landscape, had a mean size of 1.08 ha (±0.24 SD), and received no pesticide input. In total, 100 field margins and 10 grasslands were assessed once and separated into four different width classes (0.5–3.0, >3.0–6.0, >6.0–9.0, and >9.0–20.0 m) (Table 2). To minimize possible effects on density during the assessment, different size classes were determined randomly within the investigation period. Grasshopper densities were recorded by setting a catch cage (base area 0.5 m^2 [0.5 × 1 m], height 0.7 m, side surfaces covered by mesh screen) on the ground, sifting through the enclosed vegetation by hand, and collecting all grasshopper individuals present at the base area [10]. This procedure was repeated 30 times (=15 m^2) successively per sampling site at intervals of 2 m. All grasshoppers from the third instar up to adults were categorized into species level directly, according to the identification keys of Coray [21] and Oschmann [18]. Grasshopper samples were then pooled at each sampling site for further analyses. For field margins exceeding 3 m width, samples were taken at 1 m distance from the bordering field or road. On grasslands, 30 samples at intervals of 2 m were taken along a transect diagonally from one edge to the other. To account for the diurnal activity of grasshoppers, samples were taken during sunny weather conditions, after 11 AM and with temperatures above 20°C. Additionally, vegetation height and cover were recorded for each sampling site (Table 2).

Statistical analyses

The statistical analyses were performed using the software R [22]. The 48-h LR50 (the application rate of an insecticide causing 50% mortality of the test organisms) values determined during the toxicity studies were calculated with dose–response models using the "drc" package [23]. For each toxicity test, the model fitting the data best, based on Akaike's information criterion, was chosen, that is, Log-logistic or Weibull models [23]. The LR50 values were based on the insecticide field application rate (g a.i./ha); the dose received by the individual grasshopper was not measured.

Two- and three-factorial analyses of variance (ANOVA) were carried out to test differences in grasshopper density among field margin width classes located next to the types of crop investigated (i.e., grassland, cereals, vineyards, and orchards). Interactions among grasshopper density, field margin width, vegetation height, and cover were assessed based on three-factorial ANOVAs without any transformation of the

original data. Each of these statistical analyses was supplemented by a Welsh-test, which was Bonferroni-adjusted to account for multiple comparisons. Finally, statistically significant differences were assessed using the Welsh-test within one field margin width class among types of field margins. All tests were carried out on unpaired data, and $p < 0.05$ was used as the significance threshold.

RESULTS

Laboratory studies

The control mortality did not exceed 10% and thus fulfilled the validity criteria of less than 13% mortality within the control treatment for *Aphidius* [20]. Toxicity was highest for the contact exposure scenario; the combination of contact and oral exposure mostly displayed lower toxicities, except for lambda-cyhalothrin, for which the LR50s of both treatments were similar (Table 3). The contact exposure and the contact and oral exposure scenario varied by a factor of 2 for the pyrethroid deltamethrin. The oral exposure scenario always showed the lowest toxicity, whereas for dimethoate and imidacloprid the contact exposure and oral exposure scenario differed by factors of 12 and 9, respectively. For oral exposure to the insecticide pirimicarb, no LR50 value could be calculated because the toxic effects were low (field application rate [100%] resulted in 13.3% mortality). Furthermore, the combined contact and oral exposure scenario for all insecticides showed an approximately fourfold higher toxicity than oral exposure, with the exception of imidacloprid, for which toxicity differed by a factor of 2. Compared to the LR50 values from standard acute toxicity tests with *A. rhopalosiphi* and *T. pyri*, *Chorthippus* sp. showed similar ranges (Table 3).

Field monitoring

In the present study, 12 grasshopper species were found in field margins, whereas Kühne et al. [12] and Laußmann [10] detected 13 and 17 grasshopper species, respectively (Table 4). In total, 24 grasshopper species have been identified in field margins in Germany to date.

The vegetation height (ANOVA, $p < 0.0008$) and vegetation cover (ANOVA, $p < 0.0004$) had a significant impact on grasshopper density in field margins next to vineyards, but no effect in field margins next to cereals (ANOVA, height $p < 0.84$, cover $p < 0.24$) and orchards (ANOVA, height $p < 0.13$, cover $p < 0.44$). Furthermore, regarding field margin width, there was a significant influence on grasshopper density in field margins adjacent to cereals and vineyards (ANOVA, $p < 0.0001$), but not in those next to orchards (ANOVA, $p < 0.34$).

Grasslands had the highest grasshopper densities (52.2 Ind./15 m^2), but were not significantly different from field margins exceeding 9 m for vineyards (49.5 Ind./15 m^2; Bonferroni-adjusted Welsh-test, $p = 0.86$) and cereals (47.4 Ind./15 m^2; Bonferroni-adjusted Welsh-test, $p = 0.54$), whereas densities were lower in field margins bordering orchards within this width class (13.3 Ind./15 m^2; Bonferroni-adjusted Welsh-test, $p = 0.005$; Fig. 1). Grasshopper densities increased when the field margin width exceeded 6 m (in cereals) and 9 m (in vineyards), whereas those margins next to orchards showed no significance between width classes (Bonferroni-adjusted Welsh-test; Fig. 1).

In field margins >3 to 6 m located next to cereals, grasshopper densities were significantly lower than those found next to vineyards (Bonferroni-adjusted Welsh-test, $p < 0.006$).

Table 3. LR50 values of *Chorthippus* sp. after 48 h of exposure to the insecticides investigated, the model used for calculation, and the LR50 values of *A. rhophalosiphi* and *T. pyri* from the literature

| Chemical class | a.i. | Exposure scenario | Model | *Chorthippus* sp. | | | *A. rhopalosiphi* | *T. pyri* |
				LR50 48 h (g a.i./ha)	Lower 95% CI	Upper 95% CI	LR50 48 h	LR50 48 h
Phosphodithioic acid	Dimethoate	Contact	Weibull	11.41	3.97	18.84	0.01 [32]	2.24 [32]
		Contact and oral	Weibull	31.76	24.63	38.89		
		Oral	Weibull	132.26	54.59	209.93		
Carbamate	Pirimicarb	Contact	Weibull	7.87	3.32	12.42	620[a] [33]	835[b] [33]
		Contact and oral	Weibull	54.11	33.89	74.34		
		Oral		NC				
Neonicotinoid	Imidacloprid	Contact	Weibull	2.09	0.00	4.43	0.02 [34]	4.23 [34]
		Contact and oral	Log-logit	11.77	5.13	18.41		
		Oral	Weibull	19.37	8.42	30.31		
Pyrethroid	Lambda-cyhalothrin	Contact	Weibull	0.35	0.28	0.41	0.50 [35]	0.20 [35]
		Contact and oral	Weibull	0.33	0.27	0.39		
		Oral	Weibull	1.30	0.97	1.62		
Pyrethroid	Deltamethrin	Contact	Log-logit	0.10	0.07	0.13	0.55 [36]	0.01 [36]
		Contact and oral	Weibull	0.21	0.13	0.29		
		Oral	Log-logit	0.82	0.53	1.12		

[a] Higher tier 48-h barley seedlings test.
[b] Higher tier 7-d bean leaf discs test.
LR50 = application rate of an insecticide causing 50% mortality of the test organisms; CI = confidence interval; NC = no calculation possible; a.i. = active ingredient.

When field margin width exceeded 6 m, grasshopper density was significantly reduced in orchards compared with vineyards (Bonferroni-adjusted Welsh-test, $p < 0.05$; Fig. 1). Although the deviation regarding grasshopper density in this field margin width class (>6–9 m) between cereals and orchards was comparable to the differences between vineyards and orchards, such differences were not significant (Fig. 1), most likely due to the high variability and limited number of replicates, resulting in a low statistical power of 0.11.

DISCUSSION

Twenty-four grasshopper species have been found in field margins (Table 4), representing 30% of the orthopteran taxa in Germany [11]. This illustrates the importance of field margins as habitat for grasshoppers especially in agricultural landscapes; therefore, the potential risk posed by insecticide applications needs to be considered in risk assessments.

The results of the acute toxicity tests performed in the present study display the highest toxicity for the contact exposure scenario (Table 3). This can be explained by the fact that no food was offered during the first 8 h of the experiment, which may have forced *Chorthippus* sp. to increase their activity (compared with the two other exposure scenarios) while foraging for food. Increased activity on the contaminated surface of the test vessels reflects a potential increase in insecticide exposure of grasshoppers [24]. Consequently, the contact exposure scenario is suggested to represent a worst-case scenario, which potentially overestimates toxicity. The contact and oral exposure scenario, in contrast, represents more field-relevant conditions. Here, the provision of a grass mixture at the start of the experiment may have reduced the activity of *Chorthippus* sp., as sufficient food was provided without the need for extended foraging. Oral uptake of insecticides may not explain the toxic response of *Chorthippus* sp. during the contact and oral

Table 4. Grasshopper species found on field margins in Germany

| Present study (field monitoring)	Kühne et al. [12]	Laußmann [10]
Chorthippus albomarginatus	*Chorthippus albomarginatus*	*Chorthippus albomarginatus*
Chorthippus biguttulus	*Chorthippus biguttulus*	*Chorthippus biguttulus*
Chorthippus brunneus	*Chorthippus brunneus*	*Chorthippus brunneus*
Chorthippus dorsatus	*Chorthippus dorsatus*	*Chorthippus dorsatus*
Chorthippus parallelus	*Chorthippus parallelus*	*Chorthippus parallelus*
Metripotera roeselii	*Metripotera roeselii*	*Metripotera roeselii*
Tettigonia viridissima	*Tettigonia viridissima*	*Tettigonia viridissima*
	Chorthippus apricarius	*Chorthippus apricarius*
Chrysochraon dispar	*Chrysochraon dispar*	
Conocephalus discolor	*Conocephalus discolor*	
Gomphocerippus rufus		*Gomphoceripus rufus*
Oecanthus pellucens	*Leptophyes punctatissima*	*Gryllus campestris*
Phaneroptera falcata	*Metrioptera bicolor*	*Meconema thalassinum*
	Stenobothrus lineatus	*Nemobius sylvestris*
		Omocestus viridulus
		Pholidoptera griseoaptera
		Tetrix subulata
		Tetrix tenuicornis
		Tetrix undulata
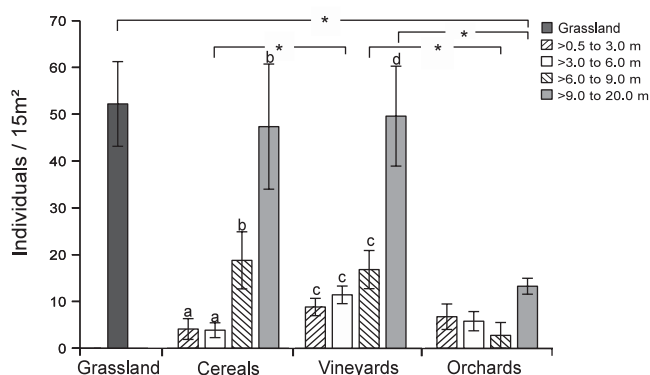
Fig. 1. Mean (± SE) grasshopper density in grassland (*n* = 10) and field margins with varying width next to cereals (*n* = 34), vineyards (*n* = 46), and orchards (*n* = 20). Lower-case letters indicate significant differences between the field margin size classes within one crop. Asterisks denote significant differences between crops within one field margin size class. Because grasslands always had a width of >9 m, the density of grasshoppers was compared with the corresponding field margin size class within each crop.

exposure scenario, as the latter always resulted in a higher toxicity compared with the oral exposure scenario (Table 3).

Because the 48-h LR50 values of *Chorthippus* sp. are in a similar range to those reported for a standard toxicity test with *A. rhopalosiphi* and *T. pyri* (Table 3), grasshoppers should theoretically be protected by the current terrestrial risk assessment for insecticides.

However, the field monitoring performed in the present study does not support this assumption. Grasshopper densities within field margins less than 9 m wide were significantly reduced irrespective of the type of crop (cereals, vineyards, or orchards) grown next to the sampling site (Fig. 1). The field margins next to cereals and vineyards showed an increasing grasshopper density with increasing width and reached grassland levels where the width exceeded 9 m. These increasing grasshopper densities could be explained by a positive relationship between habitat area and the population density [25]. However, next to orchards, grasshopper densities were independent of field margin width and did not increase at all (Fig. 1).

Furthermore, a lower grasshopper density was more associated with field margins located next to cereals compared with those located next to vineyards within the two narrow field margin width classes. However, significant differences were only obtained within the field margin width class of >3 to 6 m (Fig. 1). These differences may be explained by German regulations, which prescribe a 3-m-wide buffer zone be adhered to during pesticide application [26] (Fig. 1). Hence, these narrow field margins adjacent to cereals may have received a drift of at least 2.77% of the field application rate at a distance of 1 m from the field edge [27,28] or were even partially oversprayed. Although drift rates have been decreasing to 0.57% for cereals at a distance of 5 m from the field edge [27,28], grasshopper densities are not increasing in the field margin width class >3 to 6 m. The low grasshopper densities in field margins less than 6 m adjacent to cereals may additionally be explained by the exposure to fertilizer [29], which might be toxic to grasshopper nymphs [30]. Despite higher drift rates (8.02% at 3 m and 3.62% at 5 m distance from the field edge) [27,28], the higher grasshopper densities in field margins located next to vineyards may be explained by the low amount of insecticides applied in vineyards, where insect pest control is predominantly realized by pheromone traps in the region [15]. In addition to the possible fertilizer impact, mechanical disturbances like mowing

and overrun may explain the reduced grasshopper density in field margins less than 9 m located next to vineyards compared with grassland.

Factors like individual–area relationship, fertilizer input, or mowing, however, may not explain the large effects displayed for field margins located next to orchards, where no tendency toward an increasing grasshopper density could be observed with increasing margin width, even in the widest width class (>9–20 m) (Fig. 1). These low grasshopper densities may be explained by the high drift rates of 2.77% of the orchard application rate at a distance of 20 m (equal to 1 m for cereals) and the high amount of insecticide applications (~7.5 applications per year in apple orchards) [31]. Furthermore, insecticide applications are supplemented by up to 16 fungicide applications per year, which are often applied as tank mixtures [31]. This could lead to additive or synergistic effects not considered in the current risk assessment of pesticides.

The high number of insecticide applications and the high drift rate caused by the use of air blast sprayers in apple orchards are suggested as the main reason for the deviations in grasshopper density in field margins located next to cereals, vineyards, and orchards, although other factors cannot be completely excluded.

CONCLUSION

Our results suggest that *Chorthippus* sp. exhibit similar toxicity values as the two standard arthropods used for terrestrial nontarget arthropod risk assessment (*A. rhopalosiphi* and *T. pyri*), even when the "worst case" (contact exposure) scenario is considered. However, field monitoring revealed adverse effects on the density of grasshopper communities in field margins with a width up to 20 m, suggesting that requirements regarding the prescribed distances from the field edge are either too low or simply ignored by farmers. It is feasible that the current terrestrial risk assessment underestimates risks in agricultural landscapes because it does not account for multiple exposures during the lifetime of an organism. Furthermore, information about possible interactions between fertilizer and pesticides is absent. It is necessary to understand the causes of low grasshopper densities and also other arthropod groups in field margins to be able to adjust the pesticide regulations to restore and maximize biodiversity in agricultural landscapes.

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