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Erosion rills offset the efficacy of vegetated buffer strips to mitigate pesticide exposure in surface waters

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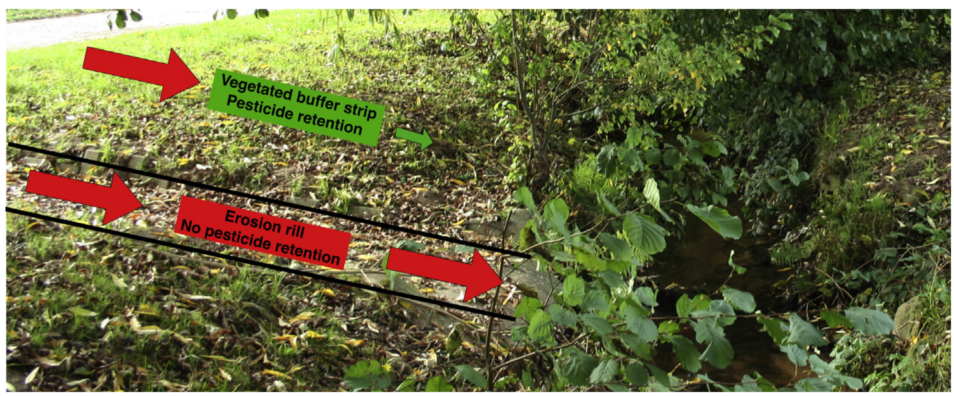
HIGHLIGHTS

- Regulatory risk assessment assumes buffer strips effectively mitigate runoff exposure.
- Erosion rills may distinctly reduce buffer strips' mitigation capacities in the field.
- Prospective risk assessment thus may underestimate pesticide surface water exposure.

GRAPHICAL ABSTRACT



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ABSTRACT

Regulatory risk assessment considers vegetated buffer strips as effective risk mitigation measures for the reduction of runoff-related pesticide exposure of surface waters. However, apart from buffer strip widths, further characteristics such as vegetation density or the presence of erosion rills are generally neglected in the determination of buffer strip mitigation efficacies. This study conducted a field survey of fruit orchards (average slope 3.1–12.2%) of the Lourens River catchment, South Africa, which specifically focused on the characteristics and attributes of buffer strips separating orchard areas from tributary streams. In addition, in-stream and erosion rill water samples were collected during three runoff events and GIS-based modeling was employed to predict losses of pesticides associated with runoff. The results show that erosion rills are common in buffer strips (on average 13 to 24 m wide) of the tributaries (up to 6.5 erosion rills per km flow length) and that erosion rills represent concentrated entry pathways of pesticide runoff into the tributaries during rainfall events. Exposure modeling shows that measured pesticide surface water concentrations correlated significantly ($R^2 = 0.626$; $p < 0.001$) with runoff losses predicted by the modeling approach in which buffer strip width was set to zero at sites with erosion rills; in contrast, no relationship between predicted runoff losses and in-stream pesticide concentrations were detected in the modeling approach that neglected erosion rills and thus assumed efficient buffer strips. Overall, the results of our study show that erosion rills may substantially reduce buffer strip pesticide retention efficacies during runoff events and suggest that the capability of buffer strips as a risk mitigation tool for runoff is largely overestimated in current regulatory risk assessment procedures conducted for pesticide authorization.

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1. Introduction

Pesticides are indispensable in global high-intensity agriculture, with elaborated regulatory frameworks and risk assessment procedures (e.g., European Commission, 2009; FIFRA, 1947) currently enforced to ensure their environmental safe use. However, recent studies proved that pesticide surface water concentrations often exceed regulatory risk assessment endpoints for both exposure (i.e., the predicted environmental concentrations (PEC) derived from exposure modeling; Knäbel et al., 2012, 2014) and effects (i.e., the regulatory threshold levels (RTL), which represent ecologically acceptable pesticide concentrations; Stehle and Schulz, 2015a, 2015b). Pesticides thus pose a severe threat to the biodiversity and integrity of aquatic ecosystems (Beketov et al., 2013; Stehle and Schulz, 2015a).

With respect to exposure pathways, runoff, in particular, has often been identified as the dominant route of diffuse pesticide surface water pollution (Bereswill et al., 2012; Schulz, 2001a; Stehle and Schulz, 2015a). The amount of pesticides entering water bodies via runoff depends on the specific characteristics of the buffer strips (e.g., width, vegetation density, soil type) separating treated agricultural areas and water bodies (Bereswill et al., 2012; Reichenberger et al., 2007), apart from other factors such as rainfall intensity, soil moisture, and slopes (Capel et al., 2001; Reichenberger et al., 2007). Buffer strips are effective mitigation measures that reduce the amounts of pollutants entering surface waters via runoff through infiltration, adsorption, interception and sediment deposition (Borin et al., 2005; Reichenberger et al., 2007; Schmitt et al., 1999). Numerous studies and reviews (see Reichenberger et al. (2007) and Zhang et al. (2010) and references therein) examined the reduction efficacies of buffer strips for pesticide runoff entries, and, despite being highly variable (i.e., pesticide reduction between 0–100%), generally reported reduction values of >60% (Reichenberger et al., 2007; Zhang et al., 2010). Vegetated buffer strips are therefore considered as an important risk mitigation tool in the prospective regulatory aquatic risk assessment of pesticide runoff required for pesticide authorization in many countries such as the EU or the US (EFSA, 2013; US EPA, 1998). Specifically higher-tier pesticide exposure modeling often incorporates pesticide runoff reduction via vegetated buffer strips for the prediction of surface water concentrations, with buffer strips width considered as the only factor determining the reduction efficacy (Bereswill et al., 2012). For example, the FOCUS Working group on landscape mitigation factors (FOCUS, 2007a, 2007b) assumes in EU regulatory pesticide exposure assessment 60% and 80% reduction in aqueous-phase pesticide mass transported in the water phase for a buffer width of 10–12 m and 18–20 m, regardless of any further buffer strip characteristics. According to EFSA (2013), PEC reductions of up to a maximum of 90% may also be considered acceptable in regulatory practice. The MAgPie (Mitigating the risks of plant protection products in the environment) working group even proposes basic pesticide runoff mitigation values of 40%, 50%, 75%, and 90% for vegetated filter strips of 3 m, 5 m, 10 m, and 20 m, respectively to be applied in the regulatory risk assessment for EU pesticide authorization (MAgPie, 2013). At a national level, the German exposure assessment incorporates pesticide reductions of up to 95% for a 20 m buffer width (Bereswill et al., 2012; Umweltbundesamt, 2015). However, these regulatory recommendations for pesticide runoff reduction by vegetated buffer zones do not consider that the amount of pesticides mitigated is strongly dependent on a number of landscape factors and buffer strips' attributes (e.g., slope, soil type, vegetation type and density, presence of erosion rills, rainfall intensity, pesticides' physicochemical properties, etc.) (Bereswill et al., 2012; Reichenberger et al., 2007). Therefore, Ohliger and Schulz (2010) concluded that characterizing the effects of buffer strips on pesticide runoff losses by width only may result in an underestimation of surface water exposure by a factor of four in German vineyards. The effectiveness of buffer strips can be substantially compromised by factors such as heavy rainfall events producing very large volumes of water in a short time (the so-called "hydrological dilemma" (Schulz, 2004)) and in particular erosion rills, which act as hydraulic by-passes through vegetated buffer strips thus preventing (uniform) laminar sheet flow resulting in a fast, directed, channelized pesticide transport through the buffer strip area into the water body (Blanco-Canqui et al., 2006; Dosskey et al., 2002; USDA, 2000). The FOCUS working group acknowledges the compromising effects of hydraulic by-passes for pesticide retention in vegetated buffer strips and refers to the urgent requirements for studies that investigate runoff-related pesticide entries into surface waters via such channeled flow (FOCUS, 2007a, 2007b). Bereswill et al. (2012) showed for an intensively cultivated vineyard region in southwestern Germany (slopes > 2%) that runoff-related in-stream pesticide concentrations were significantly and positively correlated with pesticide concentrations detected in associated erosion rills. Moreover, this study proved that buffer strip widths were of limited importance for pesticide exposure levels in streams due to concentrated runoff entries via erosion rills, which prevented laminar sheet flow of runoff across the buffer. In addition, Bereswill et al. (2013) showed for an intensively used arable agricultural region in central Germany with slopes varying between 1% and 3% that wide buffer strips do not protect surface waters from high pesticide concentrations due to the presence of erosion rills at the investigated sites.

However, apart from these findings in two German agricultural landscapes, there is a paucity of studies on the effects of erosion rills on runoff-related pesticide surface water exposure and generally on the mitigation efficacies of buffer strips for fungicide and insecticide entries into surface waters under field conditions; the vast majority of studies conducted on pesticide runoff mitigation by vegetated buffer strips were performed for herbicides and used an experimental design (i.e., experimental sites with simulated runoff) (Bereswill et al., 2012; Reichenberger et al., 2007). In order to contribute to this field of research, we performed a field monitoring campaign in the intensively-cultivated orchard catchment of the Lourens River, Western Cape, South Africa. Specifically runoff-related pesticide exposure of surface waters is well documented in this study area (e.g., Dabrowski and Schulz, 2003; Schulz, 2001b, 2004). Previous studies in the Lourens River catchment also conducted geo-data based pesticide runoff exposure assessments and successfully correlated measured pesticide concentrations after rainfall-induced runoff events with those predicted by a GIS-based runoff model (Dabrowski and Balderacchi, 2013; Dabrowski et al., 2002b; Dabrowski and Schulz, 2003), which also has been employed in the present study. However, neither of these studies attempted to establish a direct link between buffer strip characteristics except for width and pesticide contamination of the aquatic environment, nor was the presence of erosion rills incorporated in calculated predictions. Further on, no scientific study exists that compares the effects of erosion rills on in-stream pesticide exposure levels predicted by runoff models and measured field data. Therefore, the present study had the following three objectives:

1. To conduct a detailed field survey and pesticide sampling campaign in the Lourens River catchment, focusing specifically on buffer strip characteristics and the effects of erosion rills on in-stream pesticide concentrations caused by rainfall-induced runoff events;
2. to compare measured pesticide field concentrations with those predicted by a validated runoff model for the two options with or without erosion rills indicating absence or presence, respectively, of pesticide mitigation by the buffer strips;
3. to contextualize the effects of erosion rills on runoff-related pesticide entries into surface waters to the application of buffer strips as mitigation tools in current regulatory pesticide risk assessment schemes.