Management practices that reduce pesticide transport

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The use of pesticides in agriculture increased rapidly during the second half of the 20th century. Pesticides are a key part of monoculture cropping systems that suppress weeds, pathogens and insect pests, and increase yields (Aktar, Sengupta, toxicology, & 2009, n.d.; Liu, Pan, & Li, 2015). The widespread use of pesticides has led to their dispersal into the environment, including drinking water resources (Hildebrandt, Guillamón, Lacorte, Tauler, & Barceló, 2008), and food. Several studies on food safety reported mixtures of pesticide residues in food (Jardim & Caldas, 2012; Szpyrka, 2015), and indicated threats to aquatic plants, animals, and human health (Aktar et al., n.d.; Schinasi & Leon, 2014). Further, international monitoring programs on water quality show that pesticides are present in surface water and groundwater bodies with increasing concentrations (Folch, Carles-Brangarı, & Carrera, 2016; Hildebrandt et al., 2008; Larson, Capel, & Majewski, 1997; Wang et al., 2016).

If a pesticide is not transported anywhere after application there is no risk of pollution of groundwater or surface water. However, water flow dynamics, infiltration and runoff after rainfall events often transport pesticides off-site after their application (Borggaard & Gimsing, 2008; Flury, 1996; Rittenburg et al., 2015; Tang, Zhu, & Katou, 2012; Vereecken, 2005; Wauchope, 1978). Three main pathways have been identified; leaching to groundwater, subsurface flow to surface waters and overland runoff (Rittenburg et al., 2015). Local soil and climatic conditions influence which pathways are dominant within a field (Borggaard & Gimsing, 2008; Reichenberger, Sur, Kley, Sittig, & Multsch, 2019). The most important characteristics of the pesticide that influence its potential transport are their solubility, sorbtivity and half-life time (Rittenburg et al., 2015; Wauchope, 1978).

To reduce the transport of pesticides from agricultural fields, measures and good agricultural practices have been developed and implemented at farm level. The objective of this report is to investigate the effectiveness of on-field management measures for reducing diffuse pesticide pollution by transport to ground- and surface water resources. We combined (i) a synthesis of existing review papers, (ii) a meta-analysis of available data from literature and (iii) practice-based knowledge from nine case studies across Europe.

As a starting point for the literature synthesis and meta-analysis, initial data sources and literature were collected in two ways. A systematic search was performed through online databases, and a local/expert-based search was done throughout Europe. The purpose of the local search was to find studies containing valuable data which were not easily accessible through online databases. Results from major reviews since 2000 until present were synthesized including the reviews about specific measures in relation to pesticide pollution. From these reviews and extra literature that was collected for the meta-analysis, a qualitative overview is made of

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the most used and studied measures to reduce pesticide pollution of groundwater and surface waters (Table 1).

Table 1: Synthesis of literature results: effectiveness and costs of key measures. Symbols are explained below the table

Measure [source]	Effectiveness		Costs	Notes [source]
	Groundwater	Surface water		
1. Vegetated filter strips	+	+++	€€	Effectiveness depends on design, added ecological value (Arora, S. K. Mickelson, & J. L. Baker, 2003; Krutz et al., 2005; Rafael Muñoz-Carpena, Ritter, & Fox, 2019; Reichenberger et al., 2019)
2. Constructed wetlands	+	+++	€€€	Effectiveness depends on local design. (Moore, Schulz, Cooper, Smith, & Rodgers, 2002; Stehle et al., 2011; Tournebize, Chaumont, & Mander, 2017; Vymazal & Březinová, 2015)
3. Erosion reduction	-	+/-	?	(Fawcett, Christensen, & Tierney, 1994; Sadeghi & Isensee, 2001)
4. Tillage intensity	+/-	+/-	€	Effectiveness depends on local design (Alletto et al., 2010; Elias, Wang, & Jacinthe, 2018; Tang et al., 2012)
5. Drainage optimization	?	+	€	(Flury, 1996)
6. Residue management/ Mulching	?	+	€	(Alletto et al., 2010)
7. Drift reduction	na*	++	€€	High ecological value (Al Heidary, Douzals, Sinfort, & Vallet, 2014; De Snoo & De Wit, 1998; Felsot et al., 2017; Hilz & Vermeer, 2013; Otto, Loddo, Baldoin, & Zanin, 2015)
8. Crop rotations	++	++	€€	(Brown & Van Beinum, 2009; Rittenburg et al., 2015)
9. Application rate reduction	+	+	€	(Reichenberger et al., 2007)
10. Alternative pesticide	?	?	?	Depends on choice (Reichenberger et al., 2007)
11. Integrated Pest management	++	++	€€€	(Gentz, Murdoch, & King, 2010; Reichenberger et al., 2007)

NOTE: Symbols in the table indicate a scale from negative to positive with – is negative, +/- is neutral and +++ is very positive, this is a qualitative overview since quantitative data is not generally presented in the reviews. For the cost three categories were made, as follows: low (€), moderate (€€) and high (€€€). An ? indicates that no clear data is available and the evaluation of the measure is still unknown. * not available: this transport route does not exist.

In the context of preserving the quality of water resources, both surface and ground water, the reduction of pesticide transport is of vital importance (Hildebrandt et al., 2008; Rittenburg et al., 2015). In this study we show that proper management on the field can contribute to reduced pollution from overland transport, but that for transport to groundwater no readily usable agronomical measures are available. To achieve reduction of pesticide pollution in water sources, measures should also include farm system redesign, reduced inputs and regional or national approaches to facilitate a sustainable farming system.

The report concludes that: 1. The driving factors for diffuse pesticide pollution are (i) the amount and type of used pesticides, (ii) water facilitated transport through or over the soil, (iii) erosion of sediment that causes transport of sorbed particles, and (iv) spray drift during application. 2. Vegetated filter strips are the most clear measure to reduce overland transport and pollution by pesticides. Models are available to calculate dimensions and predict effectiveness for pesticide reduction. 3. Tillage practices are extensively studied in relation to off-site transport of pesticides. The analysis shows that no-till does not provide less off-site transport than conventional tillage and suggests even higher pollution in no-till systems under specific circumstances. 4. On-site measures against diffuse pollution comprise only a small part of the available approaches to reduce pesticide pollution. To obtain a sustainable system, input reduction, farm system redesign, point source mitigation and policy measures are essential to be taken into account.