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Review

The use of constructed wetlands for removal of pesticides from agricultural runoff and drainage: A review

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ABSTRACT

Pesticides are used in modern agriculture to increase crop yields, but they may pose a serious threat to aquatic ecosystems. Pesticides may enter water bodies through diffuse and point sources, but diffuse sources are probably the most important. Among diffuse pollution, surface runoff and erosion, leaching and drainage represent the major pathways. The most commonly used mitigation techniques to prevent pesticide input into water bodies include edge-of-field and riparian buffer strips, vegetated ditches and constructed wetlands. The first attempts to use wetland macrophytes for pesticide removal were carried out as early as the 1970s, but only in the last decade have constructed wetlands for pesticide mitigation become widespread. The paper summarizes 47 studies in which removal of 87 pesticides was monitored. The survey revealed that constructed wetlands with free water surface are the most commonly used type. Also, it has been identified that removal of pesticides is highly variable. The results of the survey revealed that the highest pesticide removal was achieved for pesticides of the organochlorine, strobilurin/strobin, organosphosphate and pyrethroid groups while the lowest removals were observed for pesticides of the triazinone, aryloxyalkanoic acid and urea groups. The removal of pesticides generally increases with increasing value of K_{OC} but the relationship is not strong.

Contents

1. Introduction

1.1. Pathways of pesticide input in aquatic ecosystems

The use of agricultural pesticides results in increased crop yields, but their effects are less than desirable when they leave agricultural ecosystems, especially by entering waterways (Olivier et al., 2012). Widespread use of pesticides in modern agriculture contributes to agricultural non-point source pollution in rivers and streams across the world threating drinking water resources and aquatic ecosystems (Kimbrough and Litke, 1996; Kreuger, 1998; Leu et al., 2004; Schulz, 2004; Jargentz et al., 2005; Probst et al., 2005; Zhang and Zhang, 2011). It has been found that pesticide concentrations in surface waters are related to crop and soil management practices in the catchment (Dabrowski et al., 2002; Zablotowicz et al., 2006; Anderson et al., 2013).

Moore et al. (2009) pointed out that despite some efforts to entirely eliminate pesticides from agricultural practices, numerous studies have revealed severe consequences of such action. For example, Oerke et al.

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(1994), Oerke (2006) estimated crop yield reduction up to 45–50% without the use of pesticides. However, the increasing use of pesticides for crop production protection may pose a serious environmental concern.

Pesticides may enter water bodies through diffuse and point sources, but diffuse sources are probably the most important. Among diffuse pollution, Reichenberger et al. (2007) noted 1) surface runoff and erosion, 2) spray-drift, 3) leaching, 4) drainflows (preferential flow), and 5) other sources such as atmospheric deposition and atmospheric transport of wind eroded soil.

Surface runoff is a process by which pesticides are transported in dissolved or particulate forms along the surface of sloping agricultural land (Tang et al., 2012). Surface runoff can, in principle, occur on almost all arable land, even in nearly flat terrain (Wauchope, 1978). Under average conditions, the amount of herbicides lost by movement from soil is typically <0.1% to 1% of the applied mass (Carter, 2000; Riise et al., 2004) but under certain local conditions, loss can reach up to 5% or greater (Flury, 1996; Carter, 2000). Only for strongly-sorbing pesticides with K_{OC} (Freundlich sorption coefficient normalized to soil organic carbon content) >1000 mg l^{-1} is erosion considered the main loss pathway (Kenaga, 1980; Wu et al., 2004).

Pesticides are typically applied as sprays which are formed when the liquid is atomized through a hydraulic nozzle. Therefore, the fine fraction moved by wind beyond the intended area of application is defined as spray drift (Stephenson et al., 2006). Spray drift is important especially in the areas of permanent crops (Bereswill et al., 2012; Schulz et al., 2001a), and within the last decades, it has been established that aerial pesticide drift is the major contributor to environmental pollution by pesticides besides runoff and erosion (FOCUS, 2007). Pesticide spray-drift phenomenon has been reviewed by Ucar and Hall (2001), Gill and Sinfort (2005), Reichenberger et al. (2007) and Felsot et al. (2010).

Leaching is vertical downward displacement of substances through the soil profile and the unsaturated zone, finally reaching groundwater (Reichenberger et al., 2007). Rainfall is a significant factor on pesticide leaching (Flury, 1996; Kladivko et al., 2001; Tiktak et al., 2004) — pesticide leaching generally increases with increasing annual precipitation. Steffens et al. (2013) stressed the importance of temperature-dependent processes on pesticide leaching. Leaching is also affected by organic content of the soil (Larsbo et al., 2013).

Transport of pesticides through preferential water flow through macropores to tile drainage plays an important role in the rapid transport of pesticides to surface waters (Kladivko et al., 2001; Brown and van Beinum, 2009; Tang et al., 2012). The main factors affecting the presence of pesticide in drainage waters are soil texture and structure, depth of ground water table, drainage system, pesticide physicochemical properties, rainfall distribution, pesticide application rate and application season (Reichenberger et al., 2007). Other pesticide transport sources include atmospheric deposition after volatilization (Grover et al., 1985; Messing et al., 2013), atmospheric transport of wind eroded soil (Larney et al., 1999) and point-sources such as farmyards, storage facilities or roads (Reichenberger et al., 2007).

1.2. Prevention of pesticide input in water bodies

The most commonly used mitigation techniques to prevent pesticide input into water bodies include edge-of-field and riparian buffer strips, vegetated ditches, and constructed wetlands (CWs). These Best Management Practices have been shown to be effective in pesticide removal. Filter strips are narrow strips of permanent vegetation widely prescribed to reduce contaminants in surface runoff from adjacent agricultural fields (Schmitt et al., 1999; Otto et al., 2008). A vegetative barrier is a strip of dense, tall, stiff grass that functions like a porous dam to temporarily pond runoff water, settle its sediment load, and gradually release water downslope (Dosskey, 2001). Grassed edge-of-field buffer strips have extensively been reviewed by Dosskey (2001), Lacas et al. (2005), Krutz et al. (2005), Reichenberger et al. (2007) and Liu et al. (2008).

Grassed waterways are strips of buffer installed primarily to convey excess surface runoff from fields to the field margin without causing gully erosion. Dense, low-growing grasses are used to stabilize and protect the soil surface against erosion by concentrated runoff (Dosskey, 2001). To serve this function effectively, there is usually a selection of fast growing grasses which are mowed frequently in order to prevent sward-damaging sedimentation and to reduce hydraulic roughness (Ree, 1949; Asmussen et al., 1977; Fiener and Auerswald, 2003). Also, grassed waterways reduce the velocity of overland flow and reduce peak discharge rate (Chow et al., 1999).

Bennett et al. (2005) pointed out that historically, the values and function of agricultural ditches have been ignored except for occasional dredging to remove built-up sediments and plants impeding efficient drainage. Recently, it has been shown in several studies that agricultural ditches with wetland vegetation may be useful traps for commonly used pesticides (Moore et al., 2001a, 2008; Bennett et al., 2005; Roessink et al., 2005; Dabrowski et al., 2006; Gill et al., 2008; Rogers and Stringfellow, 2009; Anderson et al., 2011).

Riparian wetlands are ecosystems in which soils and soil moisture are influenced by the adjacent stream or river. Riparian ecosystems act as a nutrient sink for lateral runoff from uplands and therefore, these wetlands are important buffer zones between agricultural lands and streams (Mitsch and Gosselink, 2000). Riparian buffer zones have long been known for effective reduction of nitrate loads (Peterjohn and Correll, 1984; Lowrance, 1992; Gilliam, 1994; Blicher-Mathiesen and Hoffmann, 1999), but these areas have also been evaluated in terms of pesticide removal (Pavel et al., 1999; Dosskey, 2001; Liu et al., 2008; Kidmose et al., 2010; Ohliger and Schulz, 2010; Bereswill et al., 2012; Lizotte et al., 2012; Karpuczu et al., 2013).

CW treatment systems are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. They are designed to take advantage of many of the processes that occur in natural wetlands, but do so within a more controlled environment (Vymazal and Kröpfelová, 2008). Recently, focus has been paid to CWs which are very effective in pesticide removal. Pesticides are removed in CWs by physical (sedimentation, flocculation, absorption, co-precipitation, precipitation), chemical (oxidation, reduction, cation exchange, hydrolysis, photolysis), biological (plant absorption and metabolism) or biochemical processes (microbial degradation) (Vink and Van der Zee, 1997; Stangroom et al., 2000; Runes et al., 2003; Imfeld et al., 2009). CWs have been used for treatment of various types of wastewater for more than five decades (Vymazal, 2011) and there are many types of CWs that could be categorized according to free water surface absence or presence, direction of flow, or types of macrophytes used.

Constructed wetlands with surface flow or free water constructed wetlands (FWS CWs) consist of basins or channels, with soil or another suitable medium to support the rooted vegetation and water at a relatively shallow depth flowing through the unit. The shallow water depth, low flow velocity, and the presence of the plant stalks and litter regulate water flow and, especially in long, narrow channels, ensure plug-flow conditions (Reed et al., 1988). Most treatment processes occur in the water column or in the litter layer on the bottom. The FWS CWs can use all types of macrophytes, i.e. free floating, submerged, floating leaved and emergent (Vymazal and Kröpfelová, 2008; Kadlec and Wallace, 2009).

CWs with subsurface flow may be classified according to the direction of flow to horizontal flow (HF CW) and vertical (VF CW). In horizontal flow CWs, wastewater is continuously fed in at the inlet and flows slowly through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone where it is collected before leaving via level control arrangement at the outlet. During this passage wastewater will come into contact with a network of aerobic, anoxic and anaerobic zones. Aerobic zones occur around