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Contrasting soil property patterns between ditch bed and neighbouring field profiles evidence the need of specific approaches when assessing water and pesticide fate in farmed landscapes

Jeanne Dollinger[a,*], Cécile Dagès[a], Anatja Samouelian[a], Guillaume Coulouma[a], Marthe Lanoix[a], Yves Blanca[b], Marc Voltz[a]

[a] INRA, UMR LISAH, 2 Place Pierre Viala, 34060 Montpellier, France
[b] IRD, UMR LISAH, 2 Place Pierre Viala, 34060 Montpellier, France

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ABSTRACT

Farm ditch networks, infrastructures designed to regulate excess water in cropped landscapes, constitute pesticide dispersal pathways or buffer zones, depending on their soil properties. Despite the key role that ditch soils play in the regulation of water and pesticide fate, their properties, especially in intermittently flooded ditches, remain poorly characterized. Therefore, our aim was to evaluate the specificity of ditch material properties to determine whether ditches require an approach that differs from that of field soils when studying water and pesticide fate in farmed landscapes. We thus analysed the variations in the pedological, herbicide sorption and flow properties of soil materials along a 2D cross-section of an intermittently flooded ditch in the Roujan catchment of southern France. We found that the upper part of the ditch bed soil profile is composed of 3 horizons that formed after the original creation of the ditch, most likely via the deposition of field-eroded particles and the accumulation of organic matter. These specific horizons have greater porosity, mostly due to their dense root systems, and contain up to 2 times more organic carbon than the neighbouring banks or field soils. Consequently, the hydraulic conductivity is greater, and the sorption of hydrophobic herbicides is up to 2 times greater in ditch bed materials than it is in soils located farther away from the ditch surface. Moreover, significant macroporal flow was evidenced in both profiles but with different contribution to the global flow. The contrasts in the hydrodynamic and sorption properties between both the ditch bed and banks materials likely results in significantly different water and pesticide infiltration patterns in ditches compared to crop fields. Given these differences, we recommend investigating the specific properties of ditch beds when studying and modelling water and pesticide fate in croplands.

1. Introduction

Ditches are human-made channels arranged as networks in cropped catchments. This type of infrastructure was originally designed to drain shallow groundwater in order to control the waterlogging of arable lands and/or to collect and rapidly carry overland flow towards catchment outlets in order to prevent soil erosion (Dollinger et al., 2015a; Levavasseur et al., 2016). The elevation of the water table relative to the water level in the ditch bed determines whether the ditch will exfiltrate water from the water table or infiltrate surface water towards the water table (Dages et al., 2009; Kao et al., 2001; Needelman et al., 2007b). In temperate humid lowlands, water tables are often located above the water level in ditch beds; therefore, exfiltration fluxes prevail, creating quasi-permanent base-flow in ditches (Bouldin et al., 2004; Debieche et al., 2006; Needelman et al., 2007b; Vaughan et al., 2008). In contrast, in catchments located in semi-arid or arid climates, water table depths are more variable, and the ephemeral flooding of ditches leads to alternation between infiltration and exfiltration conditions (Dages et al., 2009; Marofi, 1999). In both cases, ditches are zones of concentrated exchange between surface water and groundwater featuring two- or three-dimensional water flow patterns (e.g., Harvey and Bencala, 1993; Dages et al., 2009). Moreover, because surface runoff and drainage fluxes collected by ditches are potentially loaded with pesticides (Louchart et al., 2001; Tang et al., 2012; Voltz and Louchart, 2001), ditches may constitute contamination pathways that can rapidly carry pesticides towards both surface water and groundwater bodies. However, ditches have previously been reported to be efficient buffer zones for pesticide-based water pollution

* Corresponding author.
E-mail address: jeanne.dollinger@inra.fr (J. Dollinger).

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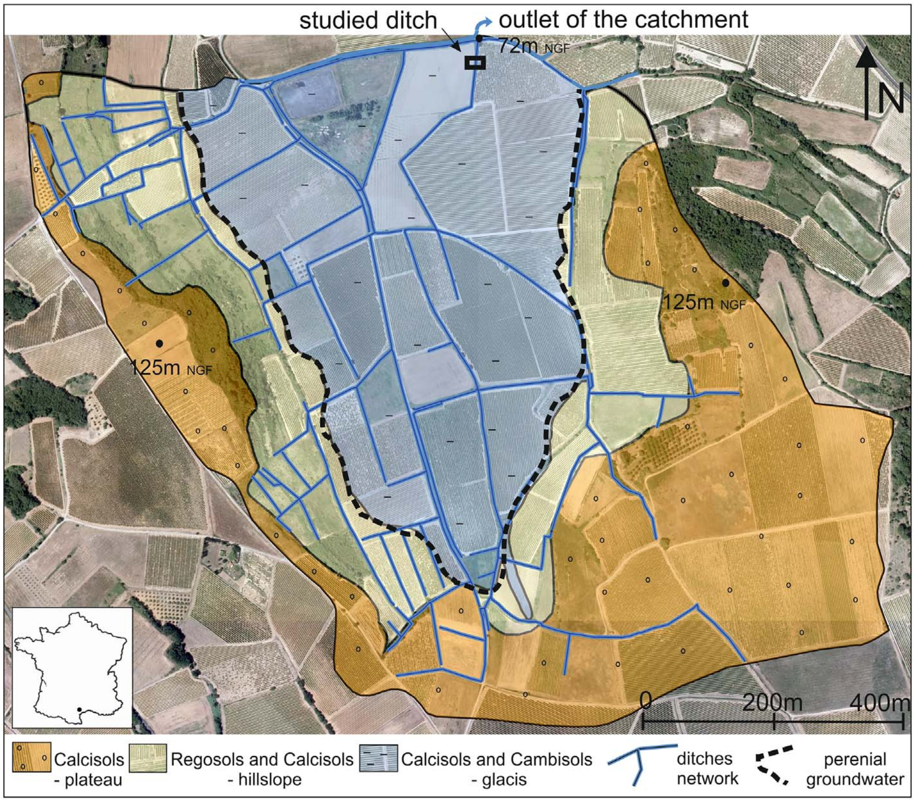

Fig. 1. The ditch network over the Roujan catchment in relation with the soils and the perennial groundwater.

(Dollinger et al., 2015a; Herzon and Helenius, 2008; Needelman et al., 2007a). The high pesticide retention capacities reported for ditches are mainly due to the sorption processes occurring on the various materials in ditch beds (Dollinger et al., 2015a; Stehle et al., 2011), especially ditch soils (Dollinger et al., 2016).

Therefore, ditches, and more specifically ditch soils, constitute key regulators of water and contaminant fluxes in cropped catchments whenever ditches are present in a landscape. This regulation role relies on several physicochemical and structural properties of the ditch materials that influence their hydraulic conductivity, their preferential flow patterns, and the sorption of contaminants, such as pesticides. However, ditch materials may differ strongly from those in neighbouring field soils for several reasons. First, because ditches are excavations, their topsoil forms from the subsoil horizons of the field soil, as well as from the deposition of field-eroded sediments and the accumulation of organic matter residue (e.g., Vaughan et al., 2008). Therefore, the topsoils of ditch beds are generally enriched in organic matter and have different textures from those of the field soil horizons located at the same depth. Second, in intensively farmed catchments, ditches often remain the only non-cropped elements in the landscape and consequently represent biodiversity hotspots (Dollinger et al., 2015a; Herzon and Helenius, 2008). Accordingly, ditches host a wide diversity of plants, rodents, insects and invertebrate species, which can potentially create soil macroporosity (Herzon and Helenius, 2008; Needelman et al., 2007b; Vaughan et al., 2008) and, in turn, produce preferential flow patterns (Dages et al., 2015). Third, ditches are subject to specific management practices that may substantially impact their physical and chemical properties. The effects of management practices on ditch characteristic are especially apparent in the case of intermittently flooded ditches as those observed by Levavasseur et al. (2014) in southern France, in which mowing, burning and chemical weeding occur at least once a year and dredging occurs once every 10 years. Some of these management operations may favour the development of an organic horizon, while dredging involves the removal of the 15- to 30-cm-thick organic matter-rich topsoil layer. Finally, ditch soils are affected by water flow patterns that are highly different from those affecting nearby field soils. Because these flows are more intense and occur in two dimensions, over time, they can produce 2D heterogeneous hydraulic properties similar to those seen in soils surrounding buried drains (e.g., Frison et al., 2009).

Despite the key role that ditch soils play in the regulation of water and contaminant fluxes, their morphologies, as well as their properties influencing water and pesticide transfer, have rarely been studied. To our knowledge, thus far, only the morphology of lowland drainage ditches in Maryland, USA, has been studied. There, Vaughan et al. (2008) and Needelman et al. (2007b) described the occurrence of ditch bed organic horizon sequences that overlie the A, BC and C horizons with weak to moderate structuration. They identified a range of pedogenetic processes involved in the formation of ditch soils, such as organic matter humification, structure formation and bioturbation. However, they did not describe the soil properties influencing the magnitude of the water and contaminant exchanges occurring between surface water and groundwater nor did they compare these properties to those of the surrounding field soils. A different sampling scheme or assessment of water or pesticide transfer parameters may however be required for ditches as compared to crop fields if their hydraulic and physicochemical properties appear to be different and contrasted.

Therefore, the main objective of this study was to analyse the 2D heterogeneity of ditch bed and bank soil materials in an intermittently flooded ditch in order to evaluate whether ditches require a different approach from that of field soils when studying and modelling water and pesticide transfer in farmed landscapes. With this aim, the variations in the pedological, sorption and flow properties of soil materials were characterized along a 2D cross-section of a representative ditch in the Roujan catchment in southern France.