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Effect of grass buffer strips on nitrate export from a tile-drained field site

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ABSTRACT

Vegetated buffer strips may reduce nutrient inputs from agricultural land into surface waters. Their effectiveness at tile-drained fields, though, remains unclear. The objective of this study was to quantify nitrate reduction in the groundwater underneath a buffer strip, to evaluate the effect of buffer strip width, and to assess their impact on nitrate loading in a drainage ditch. The study site was a tile-drained lowland field on glacial till in north-eastern Germany. The investigated grass buffer strips were 7, 3 and 1 m wide. Water levels and nitrate concentrations in 29 monitoring wells and in the adjacent ditch were measured during three winter half-years. Groundwater nitrate loads were calculated based on a simple Darcy approach.

Initial nitrate concentrations in the shallow groundwater entering the buffer strip were up to 98 mg L^{-1}, with median values ranging between 2 and 36 mg L^{-1}. Within the buffer strip, these concentrations decreased by 56–98 %. We assume that this reduction was caused by denitrification processes in two study years and dilution after snowmelt in the third year. The width of the buffer strip did not have any influence on the nitrate reduction. Presumably, site characteristics and the hydraulic conductivity are of greater importance. The groundwater nitrate load was reduced by the buffer strip, but the contribution of the groundwater to total ditch nitrate load was minor. We conclude that possible positive effects of buffer strips on groundwater quality do not ameliorate surface water quality at tile-drained field sites.

1. Introduction

The EU Water Framework Directive postulates a ‘good status’ of both surface waters and groundwater until 2015. In north-eastern Germany, in the federal state of Mecklenburg-Western Pommerania, a main problem in reaching this goal are high nitrate concentrations originating from non-point sources. More than 75% of the watercourses failed to reach a satisfying nitrate level in 2012 (LUNG, 2014).

Vegetated buffer strips provide a possibility to reduce nutrient and other pollutant inputs into surface waters and thus mitigate water quality. Located between the arable land and the water body, they act upon two input pathways: (i) They reduce surface runoff and associated transport of solutes and particles. This most effectively reduces concentrations of substances mainly transported bound to particles, such as phosphorus and pesticides (Patty et al., 1997; Abu Zreig et al., 2003; Dorioz et al., 2006; Reichenberger et al., 2007). (ii) The buffer strip enhances the distance between arable land (and agrochemicals applied there) and the watercourse, involving a longer flow distance for the groundwater and thus an enhanced retention time. This allows for more degradation of substances dissolved in the groundwater (Sabater et al., 2003; Davis et al., 2007). The buffering capacity for nitrate is controlled by microbial denitrification and microbial and plant uptake, the latter being only a temporary retention process (Haycock and Pinay, 1993; Bedard-Haughn et al., 2004). A substantial reduction in nitrate concentrations in buffer strips has been reported in many environments (Hill, 1996, Borin and Bigon, 2002, van Beek et al., 2007), but Hickey and Doran (2004) pointed out the need of experimental data ‘from buffers in the 1- to 10-m width range typically encountered on farms’.

The effectiveness of buffer strips in terms of nutrient and pollutant retention is mainly influenced by topography (Vidon and Hill, 2004), hydrogeology (Hill, 1996; Puckett, 2004) and buffer strip width (Mayer et al., 2007; King et al., 2016). Regarding vegetation type, meta-studies for both Europe and the US did not find a difference between herbaceous and forested buffer strips (Sabater et al., 2003; Mayer et al., 2007). The buffer strip width is the only other factor that can be modified. The impact of the buffer strip width has been mainly investigated with respect to sediment retention and nutrient retention in surface runoff, and it has been shown that the nutrient retention increases with buffer width (Lee et al., 1999; Schmitt et al., 1999; Abu Zreig et al., 2003; Bedard-Haughn et al., 2004). The widths investigated in these studies ranged between 2 and 16 m. A meta-analysis by Mayer et al. (2007) showed that total nitrate removal was more consistent in wide buffers (> 50 m) than in narrower ones (0–25 m), while subsurface removal of nitrate was not related to buffer width. The buffer strip area bordering

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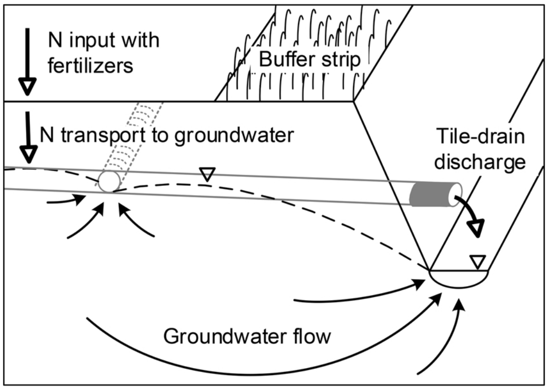

Fig. 1. Nitrate transport pathways at an artificially drained field site with a buffer strip.

the field is most important for sediment and nutrient retention (Syversen, 2002; Blanco-Canqui et al., 2004; Balestrini et al., 2011).

The effectiveness of buffer strips in artificially drained landscapes is poorly investigated. In north-eastern Germany, more than half of the agricultural area – predominantly glacial till – is artificially drained, mainly by tile drains (Koch et al., 2010). Drainage facilities may affect the functioning of buffer strips in two ways (Fig. 1). Firstly, a large fraction of the water infiltrating on the arable land is directly routed to the receiving ditch via the drainage pipes (Hirt et al., 2011; Tiemeyer et al., 2008), thus bypassing the buffer strip and its benefits. So far, Bhattarai et al. (2009) have shown for surface runoff at a drained site that nitrate and phosphorus concentrations declined through the buffer strip, but this reduction did not improve the overall water quality due to high nitrate inputs via tile-drainage. Secondly, the hydraulic gradient from the field to the receiving surface water is highly enhanced by the deepened ditch, increasing flow velocity of the groundwater and thus decreasing retention time. The hydraulic gradient in buffer strips was reported to be negatively related to nitrate reduction in a pan-European study (Sabater et al., 2003). The lowered water table in the buffer strip is also unfavourable both for plant uptake and denitrification, since the denitrification potential generally increases from the soil surface downwards. All of these aspects indicate that buffer strips may not tap their full potential at drained sites.

In the German Water Management Act (‘Wasserhaushaltsgesetz’ WHG), the buffer strip is prescribed to be generally at least 5 m wide (starting from the slope top for watercourses with a pronounced slope top; WHG § 38). Differing regulations, however, may be issued by the federal states, which typically stipulate minimum widths between 5 and 10 m (‘Landeswassergesetze’). In Mecklenburg-Western Pommerania, the minimum width had been fixed to 7 m, but was reduced in 2007 to 3 m in general, and to 1 m (temporarily) under certain preconditions. These values provided the basis for the buffer strips investigated in this study.

The objective of this study was to quantify the benefit of a buffer strip on nitrate loads from a drained lowland field, and to estimate the effect of buffer strip width on nitrate reduction in the groundwater.

2. Material and methods

2.1. Experimental site

The experimental site is located in Dummerstorf, near the city of Rostock, Mecklenburg-Western Pommerania (54°00′11″N, 12°15′07″S). The Pleistocene lowland landscape is characterized by small elevations (30–50 m a.s.l.) and gentle slopes ($< 3\%$). Long-term mean annual precipitation and temperature are 665 mm and 8.2 °C, respectively.

The cropland has a total area 23 ha and is drained by a fan-shaped network of plastic tiles (for a map of tile drains, see Tiemeyer et al., 2007). The receiving ditch has a catchment of 179 ha, which is tile-drained to approximately 80% and predominantly used as cropland (Tiemeyer et al., 2006). The drain spacing is 12–14 m at the tile-drained field and 8–22 m in the ditch catchment, the drainage depth is

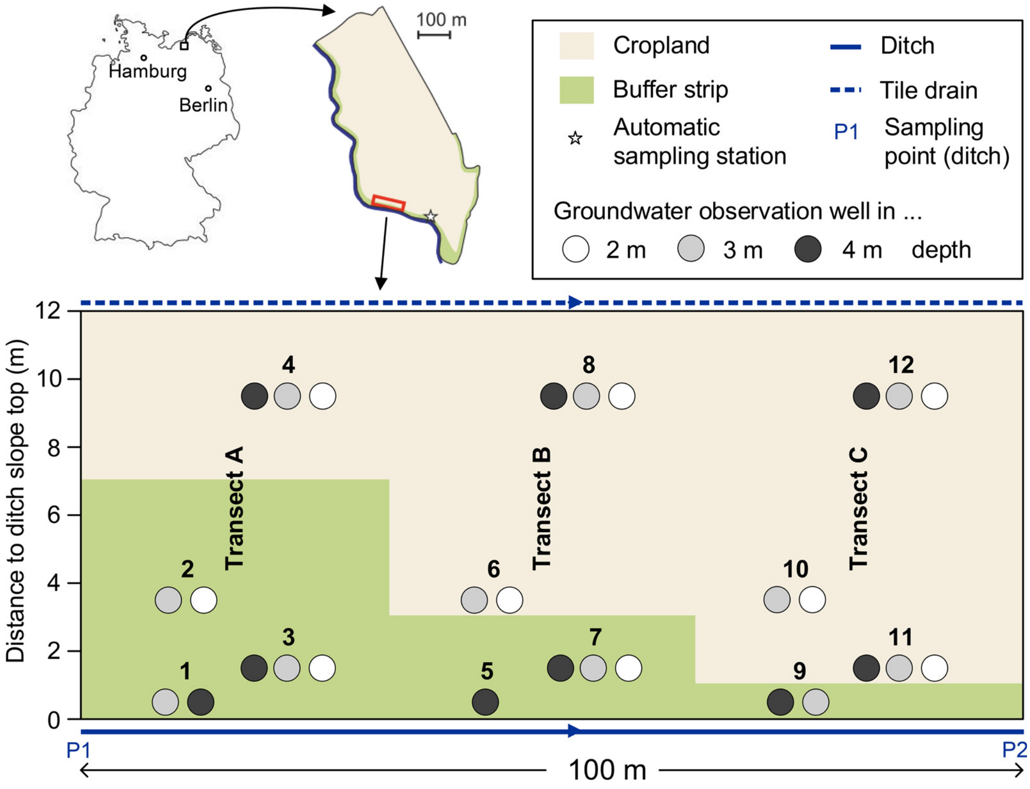

Fig. 2. Experimental field set-up with locations of monitoring wells.