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Removal of nutrients, organics and suspended solids in vegetated agricultural drainage ditch

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A B S T R A C T

Agricultural drainage is significant source of nutrients, which contributes to eutrophication of reservoirs and coastal areas. Constructed wetlands and vegetated ditches are promising techniques used for elimination of nutrients and suspended solids from agricultural drainage. While constructed wetlands have been successfully used for several decades vegetated drainage ditches have been used only recently. The current study presents the results from a two-year monitoring (2015–2016) of a naturally vegetated drainage ditch in the Czech Republic. The drainage ditch was 200 m long with *Phragmites australis*, *Typha latifolia* and *Glyceria maxima* being the dominant macrophytes growing in the ditch. Removal of nitrogen averaged 1070 kg ha^{-1} yr^{-1} with 804 kg ha^{-1} yr^{-1} being removed through denitrification of nitrate nitrogen. Plant uptake was responsible for 26.3% of the removed nitrogen. The removal of TP averaged 142 kg ha^{-1} yr^{-1} with plant uptake being responsible for 14% of the removed load. Mean removal of suspended solids amounted 20 437 kg TSS ha^{-1} yr^{-1}. Removal of BOD_5 and COD averaged 1500 kg ha^{-1} yr^{-1} and 7000 kg ha^{-1} yr^{-1}, respectively. The removal of nitrogen and organics was strongly dependent on water temperature while removal of phosphorus and suspended solids were temperature-independent. The results of this study revealed that the naturally vegetated drainage ditch has comparable treatment efficiency with constructed wetlands in terms of nutrients, suspended solids and organics.

1. Introduction

Subsurface drainage or tile drainage is a common way to keep water level low during the growing season in agricultural areas (Kladivko et al., 2004). Drainage ditches play an important role in agricultural production, however, they represent a direct link between agricultural fields and natural streams causing eutrophication of reservoirs and coastal zones (Randall and Vetsch, 2005; Engstrom et al., 2006; Smith and Pappas, 2007; Sharpley et al., 2007; Smith et al., 2008; Goswami et al., 2009; Ahiablame et al., 2010). Herzon and Helenius (2008) pointed out that in the countries of central Europe including the Czech Republic the existing drainage systems causes concern over the loss of spontaneously re-naturalized wetlands within the farmland.

Drainage ditches have been shown a suitable tool to mitigate agricultural pollution from diffuse sources in agricultural landscape due to multiple interfaces among water, sediment and aquatic vegetation (Mander and Mauring, 1997; Bouldin et al., 2004; Needelman et al., 2007; Smith and Pappas, 2007; Moore et al., 2010; Pinay et al., 2015; Collins et al., 2016; Faust et al., 2016; Iseyemi et al., 2016; Zhang et al., 2016; Moeder et al., 2017). There is a clear evidence that vegetated drainage ditches provide efficient removal of nutrients, suspended solids and organics as compared to unvegetated ditches (Jiang et al., 2007; Moore et al., 2010). Macrophytes growing in the ditches provide surface area for absorption of nutrients and microbial attachment, reduce velocity of the flow and filter out suspended solids, thus add to removal of nutrients and other agro-chemicals from the water (Gregg and Rose, 1982; Madsen and Warncke, 1983; Watson, 1987; Madsen et al., 2001; Kröger et al., 2009; Bundschuh et al., 2016). Also, benthic microalgae and epiphyte algae on macrophytes have been shown to support nutrient removal and transformations (Eriksson, 2001; Forshay and Dodson, 2011, O'Brien et al., 2014). Soana et al. (2017) concluded that the presence of vegetation in the ditches a) provides substantially higher nitrate removal than unvegetated ditches, b) results in longer retention time and c) adds labile organic carbon necessary for denitrification.

Recently, so called "two-stage" ditches were introduced (Powell et al., 2007a,b; Liu et al., 2013; D'Ambrosio et al., 2015; Roley et al., 2016; Hodaj et al., 2017, Christopher et al., 2017). A two-stage ditch involves modifications of a conventional, trapezoidal drainage ditch to better replicate the features of a natural stream through the addition of

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adjacent floodplain or benches to reduce sediment load and extend the interaction time between water, bench vegetation, and bench soil allowing larger uptake of nutrients by the vegetation and increasing denitrification rates (Hodaj et al., 2017). However, Roley et al. (2016) reported that the economic analysis revealed that wetlands are more cost-effective practice as compared to the two-stage ditches for nitrogen removal in agricultural landscape.

However, as pointed out by Castaldelli et al. (2015), the role of ditch network as a provider of ecosystem services such as nutrient cycling, biodiversity habitat, water purification, in generally not considered in the current management practices in agricultural watersheds (Herzon and Helenius, 2008; Dollinger et al., 2015).

In vegetated drainage ditches the nitrogen removal takes place as a result of plant uptake and microbially mediated transformations, among which denitrification is the dominant process (Schaller et al., 2004; Mullholand et al., 2008). Phosphorus is often found in drainage waters as particulate P, especially in areas with agricultural fields in clay and silts dominated areas (Uusitalo et al., 2000; Koskiaho et al., 2003). The processes responsible for phosphorus retention in wetlands are sediment sorption of dissolved phosphorus (Bruland and Richardson, 2006), sedimentation of particulate phosphorus (Braskerud, 2002; Koskiaho et al., 2003) and uptake by plants. Suspended solids are retained in vegetated ditches by sedimentation and filtration in the dense vegetation. Vegetation generates friction and roughness, which decrease the flow velocity and enhance the sedimentation of suspended solids (Fiener and Auerswald, 2003; Moore et al., 2010; Gumiere et al., 2011; Dollinger et al., 2015). Organics are removed through microbial degradation in the layer of decomposing plant material on the ditch bottom.

The objective of this study was to evaluate the ability of naturally vegetated drainage ditch to remove nitrogen, phosphorus, organics and suspended solids. The removal was evaluated on the basis of two-years monitoring.

2. Materials and methods

The study was carried out during the period January 2015 to December 2016 in a naturally vegetated ditch in south-central Bohemia, Czech Republic (Fig. 1). The water in the ditch is an overflow from a fishpond that is fed only by drainage waters from adjacent agricultural fields. Total length of the monitored part of the ditch was 200 m. The width of the water surface in the ditch was measured biweekly throughout the monitored period at 20 m intervals. Based on these measurements, the total flooded area was calculated as 360 m^2. The first 70 m of the ditch is only sparsely vegetated with *Epilobium hirsutum, Lythrum salicaria* and *Filipendula ulmaria* while the rest of the monitored stretch is densely vegetated with *Phragmites australis* (140 m^2), *Glyceria maxima* (64 m^2) and *Typha latifolia* (20 m^2) (Fig. 2). Depth of the water in the ditch varied between 5 and 15 cm throughout the year. The flow was measured at the fishpond discharge and at the end of the monitored ditch stretch at the day of water sampling. The average inflow and outflow flows were 0.55 and 0,51 $l\,s^{-1}$, respectively. The water loss can be attributed to evapotranspiration and potential water loss through percolation.

Composite 4-hour samples were taken biweekly from January 15, 2016 to December 8, 2016 in the fishpond outflow and in the ditch after 200 m. In the field, samples were analyzed immediately for dissolved oxygen and pH. In the laboratory, the samples were analyzed within 24 h for BOD_5, COD, total suspended solids, total nitrogen, nitrate-N, ammonia-N and total phosphorus (APHA, 1998).

Samples of three major plant species (*P. australis, G. maxima* and *T. latifolia*) were taken in four replicates within the ditch area from the quadrants 0.25 m^2 (0.5 × 0.5 m) at the end of August 2015 and 2016. The shoots were clipped at the ground level, in case of *P. australis* and *G. maxima* shoots were divided into stems, leaves and flowers (when present). The biomass was dried at 60 °C until constant weight and then

Fig. 1. Monitored drainage ditch. From top to bottom, parts overgrown with *Phragmites australis, Typha latifolia* and *Glyceria maxima*. Photo Jan Vymazal.

ground using a Fritsch Pulveristte 15 mill (Idar-Oberstein, Germany). Triplicate samples for total N were analyzed directly using a Skalar Primacs SNC analyzer (Breda, the Netherlands). Total P was determined by a colorimetric analysis after digestion in nitric-perchloric acids (Sommers and Nelson, 1972). For nitrogen and phosphorus, NIST 1547 Peach Leaves was used as the standard (National Institute of Standards and Technology, Gaithersburg, MD, USA). The triplicate measurements of the standard agreed to within 5% and NIST reference material recoveries were found in the range of 92–99%.

3. Results and discussion

3.1. Removal of nitrogen

Average TN concentrations decreased from 5.40 to 3.33 $mg\,l^{-1}$ in 2015 and from 4.64 to 2.2 $mg\,l^{-1}$ in 2016 (Fig. 2) resulting in 38.3%