NUTRIENT REMOVAL BY SUBSURFACE FLOW CONSTRUCTED WETLAND IN THE FARM MEZACIRULI

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Abstract

A pilot-scale horizontal subsurface flow constructed wetland was installed at the farm Mezaciruli, Zalenieki county, Jelgava region, in the middle part of Latvia, in August 2014 to improve stormwater quality collected from the farmyard and demonstrate applicability of constructed wetland as a convenient treatment option for contaminated surface runoff. The examined water treatment system consists of a sedimentation pond as a pretreatment plant, a water pump, a water distribution well, and a horizontal subsurface flow constructed wetland with the surface area of 160 m^2. During the observation period of 27 months (2014 – 2016) water quality parameters such as total suspended solids (TSS), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), orthophosphate phosphorus (PO_4-P), and total phosphorus (TP) were monitored and nutrient removal efficiency of the system was examined. Water samples collected at the inlet and outlet were compared. Monitoring results obtained during this study show that on average concentrations of TN and TP were reduced by 22% and 80%, respectively. However, nitrate - nitrogen concentrations on average increased by 10%, as during the time period from June, 2015 to March, 2016 reduction in NO_3-N concentrations was not observed.
Key words: Constructed wetland, Subsurface flow, Nutrients, Stormwater.

Introduction

When water quality issues in agricultural areas are discussed, mainly the negative impacts of surface runoff and subsurface drainage from arable land, pasture, grassland or wastewater discharge from livestock farming are investigated. Research by Berzina & Sudars (2010) shows that nutrient concentrations influenced by point source pollution increases in high density livestock farming catchments in Latvia. Results from the long-term monitoring in Latvia show that nitrate concentrations are often higher than the nitrate limit value set by the Nitrate Directive for nutrient leaching from agricultural land (Jansons *et al.*, 2011). The attention should be paid also on surface runoff from farmyards to assess the impacts of territories alongside farm buildings which usually can be described by a smaller catchment area comparing with the extension of agricultural lands. Farmlands may also be artificially drained or equipped with a stormwater handling system. Farmers frequently exploit their farmyards and nearest territories for temporary placing or storage of different agricultural machinery and byproducts. These areas can cause nutrients and suspended solids leakage to waters. In Latvia, which is a member state of the European Union, there is legislation related to the Nitrate Directive 91/676/EEC (1991) concerning storage and use of manure. Still there are not determined any regulations for water quality requirements of stormwater discharged from farmyard territories (LR MK, 2015). Therefore, in most cases stormwaters are directly discharged into streams as a surface runoff or through stormwater handling collector as a point source pollution causing undesirable losses of nutrients and other pollutants to water streams. That

runoff may contain high concentrations of organic matter, plant and soil particles, residues from animal feed, litter, remains of mineral and organic fertilizers etc. Stormwater may also contain oil products from agricultural machinery, impurities from manure storage, dust and other dissolved or particulate substances flushed from roofs of agricultural building and other solid surfaces at a farmyard.

To reduce such negative impacts of agriculture on water resources, farmers and regulatory agencies require information on simple, cost-effective tools to control diffuse and point source pollution of watercourses (Tanner, Nguyen, & Sukias, 2005). In Latvia, it is suggested by regulations to include in-field and edge-of-field practices in artificially drained agricultural land to control surface and drainage runoff from agricultural fields in a more environmentally friendly and sustainable way. Interception and biofiltration of surface and subsurface runoff using sedimentation ponds, bottom dams, two-stage ditches, controlled drainage and constructed wetlands (LR MK, 2014) can supplement good agricultural practices to reduce rates of nutrient losses from agricultural lands (Tanner, Nguyen & Sukias, 2005) The same attention should be focused also on water collected at farmyards. Constructed wetlands may play an important role in reducing nutrient loads to receiving waters (Tuncosiper, 2009; Valkama *et al.*, 2017). Constructed wetland is a well-known nutrient reduction measure as it is a low cost (Heistad *et al.*, 2006) and low maintenance technology used for wastewater treatment around the world (Neralla *et al.*, 2000; Vymazal, 2002), lately this measure is also recognized in Latvia. Choosing constructed wetland as a treatment plant for surface runoff, we should

comply with variation of discharge and contamination levels that generally depend on precipitation events and operations in a farmyard. Domestic septic systems are generally designed with a pre-treatment system (Heistad *et al*., 2006; Langergraber, 2007). At the farm Mezaciruli pre-treatment occurs in an open pond, which reduces a peak flow by receiving and compensating weather driven fluctuations of incoming water volume and allows the wetland to operate as evenly as possible. Pre-treatment and primary treatment is combined with elimination of solids (Vera *et al*., 2011), while subsequent treatment stages consist of a constructed wetland as a natural water treatment technology. The major removal mechanisms of nitrogen in constructed wetlands are nitrification and denitrification (Vymazal, 2002; Tuncosiper, 2009). Subsurface flow constructed wetlands require relatively shorter operation time and additional inputs in comparison to conventional treatment technologies (Vymazal, 2008). Moreover, treatment process can be operated and maintained by personnel without a specific knowledge or education (Garcia *et al*., 2005). The main purpose of this study is to inspect the treating efficiency of subsurface flow constructed wetland as a wastewater treatment plant under Latvia climate conditions in the pilot site. The objective of the article is to determine if the studied constructed wetland reduces nitrogen and phosphorus concentrations in rainwater.

Materials and Methods
Study site

A horizontal subsurface flow constructed wetland was installed at the farm Mezaciruli (56⁰ 34` 22 N, 23⁰ 29` 46 E), Zalenieki county, Jelgava region, Latvia. The study site is located in the nitrate vulnerable zone made in accordance with the criteria set out in the EU Nitrates Directive (EC, 1991), since intensity of agricultural production throughout the Zemgale region is high. The installation of the constructed wetland in Mezaciruli was started in August, 2014 with a purpose to improve the quality of stormwater collected from the hard surfaces in the farmyard territory. The examined water treatment system consists of a sedimentation pond as a pretreatment plant, a water pump, a water distribution well, and a horizontal subsurface flow constructed wetland with the surface area of 160 m². A filter material was filled in the subsurface part of the wetland at a depth of 0.9 m (Fig. 1).

There are 77% of hard surfaces covering 0.81 ha of the farmyard area, the rest are roofs of the farm buildings. Agricultural equipment and solid manure storage are covered with a polyethylene film and kept in the farmyard under the open sky. Greenhouses for growing vegetables and herbs, biogas plant, livestock buildings and office building are also located in the farmyard. Rainwater from the building roofs and paved area is collected in a stormwater capture wells or gullies and discharged through a close piping system to the sedimentation pond for accumulation and temporal storage, and further distributed to the wetland with the pump. Average concentration of suspended solids at the inlet was 83.36 mg L⁻¹. Color and turbidity of the incoming water visually differ from the water leaving the wetland at the outlet, which shows that the wetland successfully retains suspended solids.

In order to provide suitable conditions for effective wetland performance, which is particularly needed for rainwater treatment, the sedimentation pond before the constructed wetland was built. The dimensions of the sedimentation pond were estimated based on high precipitation events to ensure adequate storage capacity. The designed dimensions for the sedimentation pond are 135 m² in total area with an average water depth of 1 m. The pipe located at the outlet of sedimentation pond is equipped with a protecting sieve to prevent discharge of coarse material into the distribution well. The pump operates based on a predefined switch-on-tripping system preventing flooding from adjacent areas. Rainwater is discharged into the constructed wetland through a perforated infiltration pipe with the diameter 100 mm.

The surface area of the wetland is 1.2% of the catchment area. Common reed (*Phragmites australis*) is the most commonly used plant (Vymazal, 2002) in constructed wetlands because it is easy growing plant in moderate climate, therefore, it is chosen also in
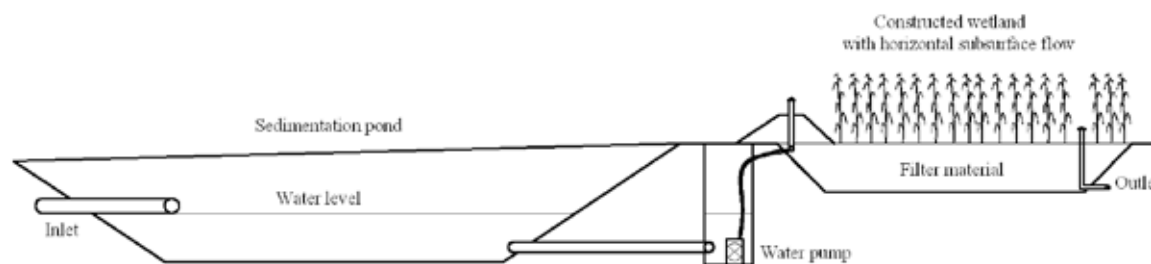

Figure. 1. Schematic drawing of the rainwater treatment system at the Mezaciruli farm.

Table 1

Analysis methods, Latvian Standards and equipment for the chemical analysis of water quality parameters

Water quality parameter	Latvian Standard	Analysis method	Equipment title
NO_3-N	FIA, ISO 13395:1996(E)	Flow analysis (CFA and FIA) and spectrometric detection	AutoAnalyzer Bran+Luebbe AA-3
NH_4-N	LVS ISO 7150-1:1984	Manual spectrometric method	
TN	LVS EN ISO 11905-1:1998	Method using oxidative digestion with peroxodisulfate	
PO_4-P	LVS EN 1189:2000	Ammonium molybdate spectrometric method	Spectrophotometer GENESYS 10S Vis
TP	LVS EN 1189:2000	Ammonium molybdate spectrometric method	

Mezaciruli. Most frequently used filtration media is gravel and crushed rock with size fractions of 4/8 and 8/16 mm (Vymazal, 2002), in Mezaciruli a filter layer consists of gravel and coarse sand with size fractions of 0.5 – 5 mm. The bottom part of the wetland is lined with a flexible waterproof membrane to prevent water leaching out of the system (Neralla *et al.*, 2000).

Monitoring of water quality

To evaluate the efficiency of the rainwater treatment system, water samples were collected using a grab sampling technique at the inlet of the sedimentation pond and at the outlet of the wetland, once or twice per month depending on water discharge. If water flow at the inlet was not observed, water sample was not collected. The monitoring period for this study was from August, 2014 to October, 2016 or 27 calendar months. Water samples were analyzed for concentrations (mg L^{-1}) of total suspended solids (TSS), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), orthophosphate phosphorus (PO_4-P), and total phosphorus (TP) according to the Latvian Standards (Table 1) at the Hydrochemistry Laboratory of Latvian Institute of

Aquatic Ecology. Methods used for the water quality parameter detection are described in Table 1.

To determine whether the nutrient concentrations change significantly after the treatment process in the wetland, data analysis offered by Statistical Package for the Social Sciences (SPSS) program was used.

Results and Discussion

The existing monitoring data show that the average concentrations of TN and TP at the inlet of sedimentation pond are 10.88 and 3.44 mg L^{-1}, respectively. Table 2 summarizes the average values and standard deviations calculated for the water quality parameters at the inflow and outflow of the rainwater treatment system. The results of standard deviations indicate that nutrient concentrations at the inflow and outflow vary greatly. Ammonium-nitrogen concentrations were generally high and quite similar at the inflow and outflow. Almost all of the monitored water quality parameters showed reduction. During the study period the concentrations of TN and TP was reduced on average by a 22%, and 80%, respectively. However, the concentrations of nitrate - nitrogen increased on average by 10%. Notably that during the

Table 2

Average, standard deviation and reduction values for the water quality parameters

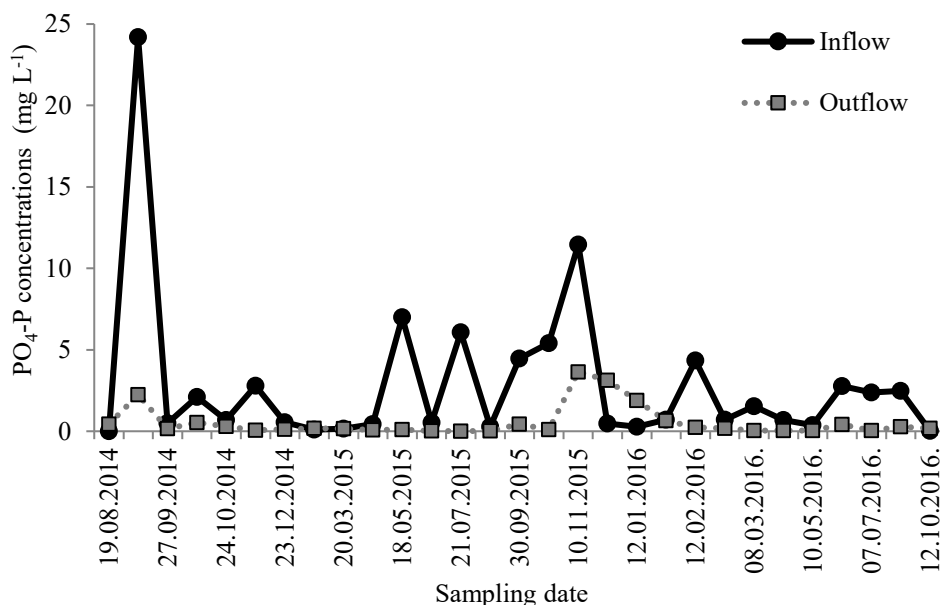| Water quality parameters	Average concentrations at the inflow	Average concentrations at the outflow	Reduction, %
NH_4-N	1.78 ± 1.71	1.61 ± 1.17	**-9**
NO_3-N	2.96 ± 4.88	3.26 ± 4.73	10
TN	10.88 ± 8.29	8.49 ± 4.49	**-22**
PO_4-P	2.88 ± 4.88	0.54 ± 0.94	**-81**
TP	3.44 ± 5.67	0.67 ± 1.08	**-80**
TSS	83.36 ± 137.72	32.83 ± 22.14	**-61**

Figure. 2. PO_4-P concentrations (mg L^{-1}) during the study period.

time period from June, 2015 to March, 2016 reduction in NO_3-N concentrations was not observed.

To determine whether the nutrient concentrations change significantly after the treatment process in the wetland, ANOVA analysis was used. Null hypothesis was that wetland did not have a statistically significant impact on nutrient concentrations (Valkama *et al.*, 2017). The results of ANOVA analysis showed that TP concentrations at the inflow were significantly different from TP concentrations at the outflow if the statistically significant differences were examined at a significance level of 0.05. Similarly PO_4-P concentrations at the inflow were significantly different from PO_4-P concentrations at the outflow at a significance level of 0.05. However, the difference was not significant for the concentrations of TN (α = 0.177), NO_3-N (α = 0.814), and NH_4-N (α = 0.668) when results from the inflow and outflow were compared.

Temporal changes in the concentrations of orthophosphate - phosphorus in the rainwater treatment system are presented in Fig. 2. The reduction efficiency depends greatly on the concentration of PO_4-P measured at the inlet. As PO_4-P concentration increases at the inlet, the reduction efficiency decreases. The study of Heistad *et al.* (2006) showed similar findings. Two episodes supporting this conclusion were observed in September 12, 2014 and November 10, 2015 when the highest concentrations of PO_4-P at the inlet were measured. In general, the system has performed well with respect to PO_4-P and TP removal throughout the study period.

The subsurface flow wetland did reduce the concentrations of TN in 52% of the sampling events (Fig. 3). The highest concentration of TN, along with

the highest reduction rate was observed during the relatively dry period in October, 2015.

One of the factors strongly affecting the performance of constructed wetlands is vegetation (Vymazal, 2002). Garcia *et al.* (2005) have found that gravel of fine composition promotes greater growth of macrophytes, thus increasing ammonium retention through biomass uptake. Our results also showed that ammonium – nitrogen concentrations had a tendency to increase in vegetation period. The study of Kuschk *et al.* (2003) demonstrated the similar effect of seasonal temperature changes on the nitrogen elimination rates. Average air temperature during the warm season (April-September) was 13.7 °C, while during the cold season (October-March) air temperature decreased to 1.9 °C. Meteorological data obtained from Auce meteorological station.

Ammonium - nitrogen entering the wetland can be transformed into nitrate - nitrogen on the way to the outlet (Xinshana, Qina, & Denghuab, 2010). When different forms of nitrogen (Wojciechowska, Gajewska, & Ostojski, 2017) in water sampled at the inflow and outflow are analyzed, an organic form of nitrogen (TN - NH_4-N - NO_3-N = N_{org}) was 48% and 46% for the inflow and outflow, respectively. In contrast, the proportion of NH_4-N in TN was 21% and 22% at the inflow and outflow, respectively. Similar results were detected also for the proportion of NO_3-N in TN - 31% and 33% at the inflow and outflow, respectively. These results indicate that nitrogen uptake might be the primary nitrogen removal mechanism in this constructed wetland, but further research is needed to support this statement. Most likely phosphorus is absorbed by the filter material.
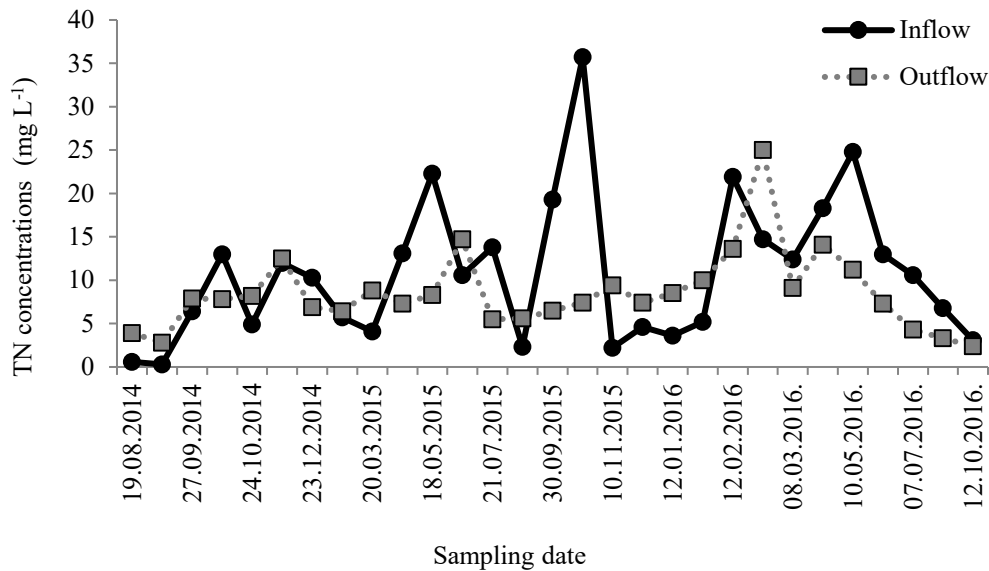
Figure. 3. TN concentrations (mg L⁻¹) during the study period.

Since the water pump is operated depending on the water level in the sedimentation pond, there may be cases where the water level maintains the pump on operating mode for the prolonged time period. A 19 m long infiltration tube inside of the wetland currently is able to distribute 0.72 m³ of water. This amount of water can be infiltrated in 17 minutes, limited by the filtration coefficient of the filter material which is 60 m per day for coarse sand. Extended and intensive rainfall events or rapid snow melting can promote the situation when the surface of the wetland is covered with an open water layer which slowly infiltrates vertically into the filter. Presence of such conditions may negatively affect the efficiency of nutrient removal processes in the wetland.

Conclusions

This study showed that subsurface flow constructed wetland treating rainwater from agricultural farmyards has a potential to reduce nitrogen and phosphorus concentrations. Higher removal efficiency at the studied wetland was observed for phosphorus compounds as these compounds are mainly retained through physical processes such as filtration and absorption occurring in filter media. The reasons why nitrate – nitrogen concentrations increase after the constructed wetland remain an open question. Overall, additional and more detailed investigations are needed to understand processes behind nutrient removal in subsurface flow wetlands.

Acknowledgements

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