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Nitrogen losses from small agricultural catchments in Lithuania

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ABSTRACT

A study of precipitation, runoff and total annual nitrogen concentrations in streamflow was performed in three small stream catchments ($A = 1.66 \div 14.2\ km^2$) located in western, middle and southeastern parts of Lithuania during 1996–2010. The studied catchments belong to different geographic districts of Lithuania in which climate, soil, land use and farming conditions differ. The main objective was to present and analyse long-term data collected from three water-quality monitoring sites and to investigate the impact of various factors that may affect nitrogen losses.

The results revealed the complex and dynamic nature of the various factors affecting nitrogen losses. The nitrogen contribution from wet deposition varied from 6.3 to 56.7 kg ha^{-1} per year and it was found to be significant factor controlling nitrogen export from the catchments. However, the proportions of arable land and pasture within the catchment, as well as the soil conditions were also found to be important.

The annual runoff varied from 54 to 403 mm and exhibited strong spatial patterns among the catchments. The highest runoff was observed in the stream in southeast Lithuania, where sandy soils and a larger groundwater supply prevail. High runoff was also found typical in the stream in western Lithuania, the catchment of which received greater precipitation, exhibited hilly topography and a large drained area. The smallest runoff and highest instream nitrogen concentration (flow-weighted annual average was 7.0 mg l^{-1} compared with 3.3 and 2.8 mg l^{-1} in the other streams) was observed in the stream in the middle Lithuanian lowland, where more intensive agricultural activity occurs. The average annual load of total nitrogen in the stream in mid-Lithuania was 15.3 kg ha^{-1}, compared with 11.8 and 7.0 kg ha^{-1} for the streams in the southeast and west, respectively.

The 15-year data did not show any statistically significant trend either in the dynamics of the annual nitrogen concentration or in the annual nitrogen load of the streams.

1. Introduction

The nitrogen (N) cycle is one of the most important processes in nature and without nitrogen, life is impossible. However, during the last century, human contributions to the nitrogen cycle began to increase drastically. According to Canfield et al. (2010), probably no phenomenon in the last 2.5 billion years has affected the nitrogen cycle more than human inputs. Altogether, human activities currently contribute twice as much terrestrial nitrogen fixation as do natural sources and provide around 45% of the total biologically useful nitrogen produced annually on Earth. While nitrogen is an element that is essential to life, it becomes an environmental problem at high levels (Stoate et al., 2009; Povilaitis et al., 2011). Excess nitrogen is an important cause of eutrophication in freshwater ecosystems, estuaries and coastal areas (Lepistö et al., 2006; Savage et al., 2010). As stated by HELCOM (2009, 2013), in the Baltic Sea catchment area, the major anthropogenic source of waterborne nitrogen is diffuse input. This constitutes 71% of the total load into surface waters within a catchment area. Agriculture alone contributes about 80% of the reported total diffuse load. Although there appears to be a slightly decreasing trend in riverine loads of both nitrogen and phosphorus in the Baltic Sea catchment, the target input levels indicated in the Baltic Sea Action Plan have not been attained for either nutrient. This certainly indicates that further efforts are necessary to reach the goals.

Numerous studies have demonstrated that losses of nitrogen from agricultural land to water can be substantial. For example, the average leaching of root zone nitrogen in Sweden is estimated to be 22 kg N ha^{-1} per year (Johnsson and Hoffmann, 1998; Hoffmann

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et al., 2000), in Norway it is 36 kg N ha^{-1} per year (Bechmann et al., 1998) and it is up to 80 kg N ha^{-1} per year in Denmark (Dalgaard et al., 2011). Long-term monitoring data indicate that annual losses of total nitrogen from agricultural catchments can vary from 10 to 77 kg N ha^{-1} in Norway (Bechmann et al., 2008), 5–30 kg N ha^{-1} in Denmark (Kronvang et al., 2005), 2–41 kg ha^{-1} in Sweden (Larsson et al., 2005; Kyllmar et al., 2006) and 5–35 kg N ha^{-1} in Estonia (Iital et al., 2008). According to Jansons et al. (2003) and Lagzdins et al. (2012), nitrogen losses in Latvia may vary from 2 to 30 kg N ha^{-1} per year. Nitrogen losses are always larger in drained rather than in undrained soils (Povilaitis, 2000; Tiemeyer et al., 2006). Behrendt and Bachor (1998) estimated that 47% of nitrogen emissions to the Baltic Sea from the state of Mecklenburg-Vorpommern in northeastern Germany originated from tile drainage. At the field scale, annual nitrate-nitrogen losses of up to 105 kg N ha^{-1} through tile drains have been reported (Vinten et al., 1994; Kladivko et al., 1999). Annual losses of 25–101 kg N ha^{-1} via drainage systems have also been observed in Lithuania (Povilaitis, 1998; Bučienė, 2003; Šmitienė, 2008). Clearly, such large inputs of nitrogen to both surface and groundwater are a matter of great concern.

Various studies have demonstrated that different factors may affect nitrogen losses. Pionke et al. (2000), Vagstad et al. (2000) and Vuorenmaa et al. (2002) all found that hydrological flow processes play an important role in nitrogen losses. Meanwhile, Kyllmar et al. (2006) have indicated that the increase in nitrogen losses can be stimulated by mild winters, abundance of precipitation, presence of sand and organic soils, livestock numbers and plant production systems. These findings have been confirmed by several studies in Lithuania (Gaigalis and Račkauskaitė, 2001; Gaigalis et al., 2003; Gudas and Povilaitis, 2013). According to Šileika et al. (2005), the capability of plants to assimilate mineral fertiliser and the subsequent loss of nitrogen depends largely on soil humus content and soil texture. Šileika and Gužys (2003) have found that nitrate-nitrogen leaching depends highly on the rate of soil fertilization. Chomčenko et al. (2000), Rudzianskaitė (2000) and Adomaitis et al. (2005), while investigating the leaching of nutrients in the karst region of Lithuania, determined that the largest amounts of nitrate-nitrogen are leached from arable land and the least from pasture. Investigations by Bučienė and Gaigalis (2012) revealed that nitrogen in drainage water might positively correlate with the concentration of these ions in precipitation. Povilaitis (2003, 2006), while analysing water-quality changes in Lithuanian rivers in 1990–2002, concluded that riverine nitrogen concentrations were determined mainly by soil and runoff conditions within the catchment.

Although the cited studies provide useful knowledge, there is still a lack of information regarding the dominant processes governing nitrogen loss from land to water in catchments with prevailing agricultural activities. It is imperative to obtain data that are more comprehensive to improve decision-making and to implement mitigating measures. Therefore, the main objective of this research is to investigate the impact of various factors that affect nitrogen losses from small catchments in Lithuania. Because the information on nutrient losses in post-Soviet countries is very limited, the idea of the study is to present and analyse the long-term data collected from three water-quality monitoring sites located in different geographic districts of Lithuania.

2. Study areas

Monthly data on precipitation, air temperature, water discharge and streamflow total nitrogen concentrations from three monitoring sites in the Lyžena, Graisupis and Vardas stream catchments within the period 1996–2010 were used in this study. The study catchments are located within the Baltic Sea drainage area where the climate is transitional between maritime and continental. The area of the catchments varies from 1.66 to 14.2 km^2. Each catchment represents a typical physical geographical area of Lithuania: the western Samogitian upland (Lyžena), the middle Lithuanian lowland (Graisupis) and the southeastern Baltic upland (Vardas). The locations of the water-quality monitoring sites together with the layouts of the catchments are shown in Figs. 1 and 2, respectively. The basic soil, land use and other characteristics of the catchments are summarized in Table 1.

The Graisupis river catchment is a flat area with a slight slope declining from the northwest to the southeast. The Lyžena and Vardas catchments are hilly areas lying at altitudes of 120–180 m a.s.l. The length of the Graisupis stream from the headwaters to the downstream monitoring site is 7.6 km; the equivalent lengths of the Vardas and Lyžena streams are 6.6 and 2.8 km, respectively.

The prevailing soil within the catchments is loam and sandy loam. In the Graisupis catchment, the proportion of loam soil is the highest (57.5%) and sandy loams and sands account for 40.2%. About 88% of the soils within the catchment are distinguished by neutral soil reaction (pH 6.0 and higher) and only 2.1% are acidic (pH 5.0 and lower). The soils in the Vardas catchment are lighter: sandy loams and sands account for 71.4%, peat soils for 15.4% and loams for 10.3%. The soils in the Vardas catchment are more acidic: soils with neutral reaction comprise 49.1%, while acidic soils constitute 21.3%. In the Lyžena catchment, light loamy soils prevail. Light loams account for 66.1%, sandy loams for 29.1% and peat soils constitute 4.5%. Soil acidity in the Lyžena catchment is almost the same as in the Vardas: neutral reaction soils account for 45.8% and acidic soils account for 21.0%.

The land use structure in the study catchments did not change during the analysed period (1996–2010). Arable land dominates in the Graisupis catchment, whereas land under pasture prevails in the Vardas and Lyžena catchments. The majority of pastures in these catchments are not intensively grazed, neither have they been ploughed for many years. In all the catchments, arable land and pastures have been completely tile drained (5.0–7.5-cm pipe diameter, 16–28-m drain spacing, 0.8–1.2-m drain depth with the line slope of 0.004–0.012 m m^{-1}).

Mixed type agricultural production prevails in the Graisupis catchment. Plant production (cereals and sugar beets) and animal husbandry are the dominant agricultural activities within the catchment. There is only one large-scale private farm in this area holding more than 150 cows, and one agricultural enterprise with a cowshed for 300 cows and a pigsty for 1250 pigs. The average animal density in the catchment is 0.87 animal units (AU) per hectare of agricultural land. In contrast to the Graisupis catchment, there are only a few small farms with up to 10 cows in the Vardas and Lyžena catchments, where the animal density is 0.44 and 0.58 AU ha^{-1}, respectively. About 18% of agricultural land in the Graisupis catchment is comprised of soils distinguished by medium (61–90 kg N ha^{-1}) inorganic nitrogen content in the 0–40-cm soil layer, while the area of such fertile soils in the Vardas and Lyžena catchments accounts for 5.9% and 3.3%, respectively. The remaining part is comprised by soils of either very low (0–30 kg N ha^{-1}) or low (31–60 kg N ha^{-1}) inorganic nitrogen content (Mažvila, 1998).

There are no large urban settlements within the study areas and thus, agriculture remains the main anthropogenic source of waterborne nitrogen. However, comprehensive data on the annual fertiliser (mineral + organic) application is available only for the Graisupis catchment (Fig. 3). Although there is a large gap in the data between 1997 and 1999, the dynamics indicate increasing rates of fertiliser application from 65 to 109 kg N ha^{-1} until 2004. From 2005, the rates began to decrease. The average rate of fertiliser application for the study period in the Graisupis was 93.7 kg N ha^{-1} per year. Very limited data show that in 1998 and 2000, fertilization rates in the Vardas catchment were 38.0 and 39.4 kg N ha^{-1} per