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Rice agriculture increases base flow contribution to catchment nitrate loading in subtropical central China

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ABSTRACT

Base flow is recognized as an important hydrological pathway for NO_3^-–N export, however, the base flow contribution to NO_3^-–N loading in rice agriculture catchments remains unknown. In this study, stream discharge and NO_3^-–N concentration were observed in two contrasting rice agriculture catchments (named Tuojia and Jianshan) in subtropical central China between November 2010 and December 2013, to quantify the base flow contribution to NO_3^-–N loading and determine its relationship with rice agriculture. The results suggested that Tuojia produced more base flow (727.0 vs. 426.5 mm) and had higher base flow contribution to stream discharge (41.9% vs. 28.4%) than Jianshan did during the observation period, due to the more groundwater recharge associated with the higher areal proportion of rice agriculture in Tuojia. The average flow-weighted NO_3^-–N concentration in the base flow was higher in Tuojia than in Jianshan (1.43 vs. 1.07 mg N L^{-1}), because rice agriculture could result in obvious N leaching into groundwater system. The NO_3^-–N loading via the base flow reached 0.27 kg N ha^{-1} $month^{-1}$ in Tuojia, which contributed 36.5% of the NO_3^-–N loading via the stream discharge. These values were much greater than 0.12 kg N ha^{-1} $month^{-1}$ and 27.3% in Jianshan. The more NO_3^-–N loading and greater base flow contribution in Tuojia were attributed to the more base flow and higher NO_3^-–N concentration in base flow associated with the intensive rice cropping. Specifically, the base flow contribution to the NO_3^-–N loading was greater during the fallow seasons than during the rice-growing seasons, likely due to the NO_3^-–N "landscape memory" effects from previous rice cropping seasons. Therefore, NO_3^-–N reduction practices in the rice agriculture catchments should be applied to mitigate the base flow contribution to NO_3^-–N loading in subtropical central China.

1. Introduction

Significant nitrate (NO_3^-–N) loading from agricultural catchments is one of causes of excessive nutrient enrichment and eutrophication in streams (Dodds and Welch, 2000; Dodds and Welch, 2000a). Base flow is defined as the sum of deep subsurface flow and delayed shallow subsurface flow and is recognized as one of the dominant hydrological pathways for NO_3^-–N migration toward streams in agricultural catchments (Leon et al., 1998; Arnold et al., 2000; Schilling and Zhang, 2004). Although numerous studies have reported significant base flow contribution to water quality deterioration in agricultural catchments (Leon et al., 1998; Schilling and Zhang, 2004), few studies have quantified base flow contribution in agricultural catchments or determined its relationship with agricultural land use (Schilling and Libra, 2000). A more thorough understanding of base flow contribution to NO_3^-–N loading in agricultural catchments would allow us to reduce or prevent NO_3^-–N discharge into streams (Schilling and Zhang, 2004).

Base flow is often considered as a gradual process in natural ecosystems, relative to surface runoff (Arnold et al., 2000); thus, the effect of base flow on NO_3^-–N loading is often neglected (Reay et al., 1992; Leon et al., 1998). In fact, subsurface NO_3^-–N, which is hardly adsorbed by soils and easily dissolved in water, can be exported into stream systems through base flow process (Bohlke and Denver, 1995; Leon et al., 1998; Schilling and Zhang, 2004). Leon et al. (1998) reported that NO_3^-–N loading via base flow

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accounted for approximately 26–100% of the catchment NO_3^-–N loading (median: 56%) within the Chesapeake Bay catchment of the Middle Atlantic Coast, USA. Schilling and Zhang (2004) reported that NO_3^-–N loading largely occurred through base flow into the Mississippi River in two central Iowa catchments in the USA. However, because base flow and the resulting NO_3^-–N loading processes are largely affected by natural factors such as climate, soil, topography and land use (Arnold et al., 2000; Schilling and Zhang, 2004) and anthropogenic activities such as socioeconomic conditions, fertilization, irrigation and tillage in catchments (Krupa et al., 2011; Wang et al., 2014a,b), the contribution of base flow to NO_3^-–N loading may vary significantly across agricultural catchments. Hence, it should be systematically quantified.

NO_3^-–N loading via base flow varies significantly depending on agricultural land use types within catchments (Leon et al., 1998; Schilling and Zhang, 2004), because different agricultural land use types affect N leaching into groundwater system (Jalali, 2005; Wang et al., 2011), water supply and base flow capacity (Arnold et al., 2000). Rice (*Oryza sativa, L.*) agriculture is a periodically flooded agricultural land use type, covering 161 million ha of land worldwide (Krupa et al., 2011; Deng et al., 2012; Wang et al., 2014a). Rice agriculture usually requires large quantities of N fertilizer to maintain high yields, which has resulted in severe nutrient pollution in the water bodies of agricultural catchments internationally (Kim et al., 2006; Bouman et al., 2007; Wang et al., 2014a). While previous studies have attributed severe nutrient pollution in water bodies to large amounts of surface irrigation/drainage and annual N fertilizer application in rice agriculture catchments (Wang et al., 2014a), few studies have examined the potential disruptions caused by base flow and the resulting NO_3^-–N loading in rice agriculture catchments. Chen and Liu (2002) found that periodically flooded paddy fields can serve as a major source of groundwater recharge in rice agriculture catchments. Tang (2005) reported that average NO_3^-–N concentration in groundwater reached 8.88 mg N L^{-1} in a rice agriculture catchment in Jiangxi province, China. Our records showed groundwater NO_3^-–N concentrations as high as 49.50 mg N L^{-1} in the rice agriculture catchment of Hunan province, China (Wang et al., 2015), which is considerably higher than the recommended drinking water standard set by the World Health Organization (NO_3^-–N <10 mg N L^{-1}) (WHO, 2011). These results show that rice agriculture may increase NO_3^-–N leaching into groundwater and result in NO_3^-–N loading via base flow process. However, until now, the base flow contribution to NO_3^-–N loading in rice agriculture catchments has remained unclear.

Thus, it was hypothesized that base flow is a dominant hydrological pathway of NO_3^-–N loading in rice agriculture catchments. Stream discharge and NO_3^-–N concentration in stream water were monitored in two rice agriculture catchments in subtropical central China for November 2010–April 2013. The objectives of this study were to (i) quantify the amount of base flow in rice agriculture catchments and (ii) evaluate the base flow contribution to catchment NO_3^-–N loading.

2. Materials and methods

2.1. Geographic location and climate

The Jinjing catchment is located at the Changsha Research Station for Agricultural & Environmental Monitoring (27°55′–28°40′N, 112°56′–113°30′E, elevation of 46–452 m) of the Chinese Academy of Sciences (CAS) in Hunan Province, China (Fig. 1). The area has a typical subtropical monsoon climate with an annual mean air temperature of 17.5 °C and a mean annual rainfall of

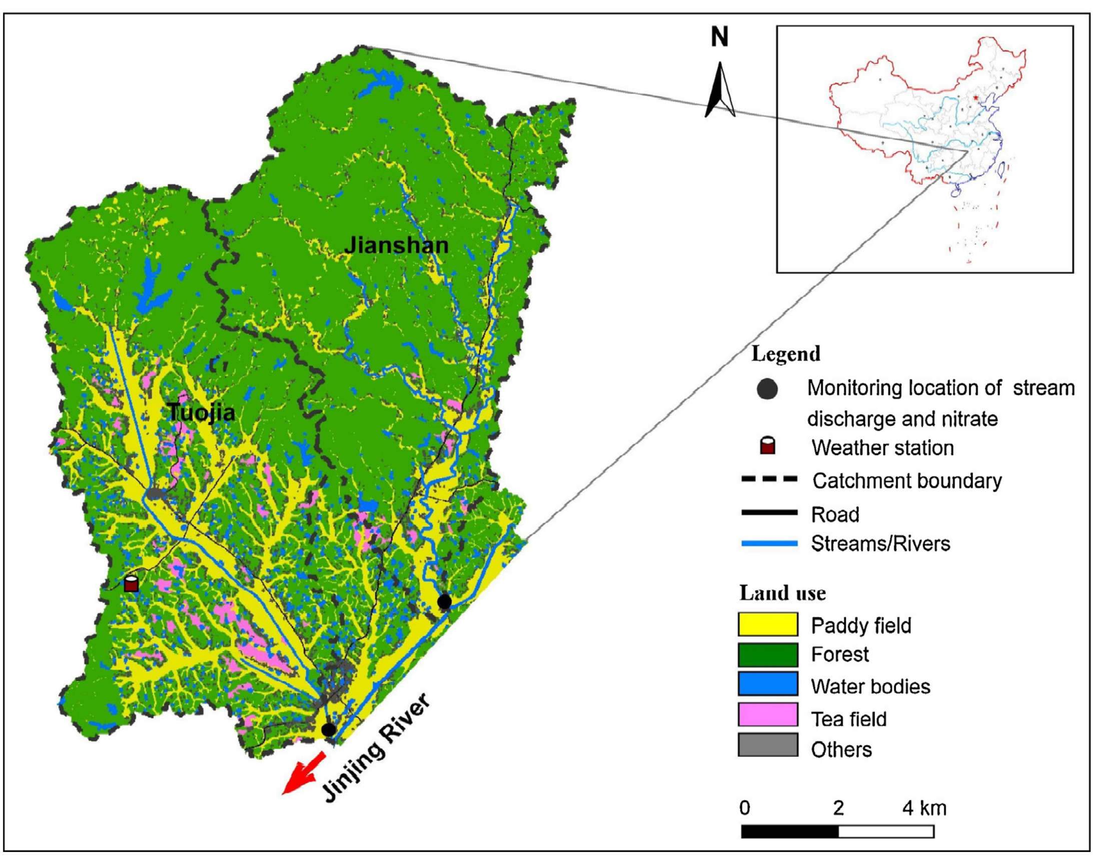

Fig. 1. Land use types and observation locations in the two catchments.