# Variation of nonpoint-source nutrient concentration in interflow affected by winter processes in Shenyang, China

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**Abstract** In the mid-latitude climatic region (35–65°), long-term winter processes with freeze–thaw cycles (FTC) may have profound effects on nutrient transformation and soil structure, and consequently impact nonpoint-source (NPS) nutrient concentration in interflow. Under realistic soil temperature fluctuations, concentrations of nitrogen (N) and phosphorus (P) in interflow were investigated before winter and after winter. At all sites, N and P concentrations varied markedly before and after winter. TN interflow fluxes were 5 times higher after winter in arable land and grassland than before winter, whereas TP concentrations were lower. There was a consistent variation between arable and grass before and after winter. These results are mainly attributed to effects of winter processes on N and P accumulation and transformation, and soil structure. Soil frost causes a reduction in runoff and in nutrient uptake by vegetation, causing TN and TP concentrations in soils to increase during winter. Further, FTC cause the disruption of soil structure, and induce more micro-aggregates. This effect releases more N from the destroyed aggregate. In contrast, the TP concentration decreased, which is likely due to the adsorption of P on exposed new surfaces and the high adsorption capacity of dissolved P. This study suggests that NPS nutrient concentrations in interflow are impacted by winter processes in the mid-latitude climatic region, and that interflow should be considered as an important hydrological pathway of TN loss.

**Key words** nonpoint-source pollution; freeze–thaw cycles; nitrogen; phosphorus; interflow; Shenyang, China

## INTRODUCTION

The nonpoint-source (NPS) contribution of nutrients – nitrogen (N) and phosphorus (P) – is a major source of water pollution world-wide. NPS nutrient loads have caused the widespread eutrophication of lakes, rivers and coastlines (Carpenter *et al.*, 1998). The environmental behaviour of NPS nutrients is highly variable due to spatial and temporal variations in meteorological conditions, mainly temperature and precipitation (intensity and magnitude). For the mid-latitude climate regions (35°–65°), overwinter processes with freeze–thaw cycles (FTC) have strong effects on nutrient accumulation and transformation, and soil physical properties (Kvaerno & Oygarden, 2006; Matzner & Borken, 2008). Consequently, they may impact nutrient concentrations in downstream aquatic ecosystems after winter. Furthermore, these effects probably contribute a greater nutrient "dosage" to surface waters, which can seriously degrade aquatic ecosystems and impair the use of water for drinking, industry, recreation and other purposes.

There have been many studies on nutrient losses at the watershed scale. It was suggested that the effects of winter processes on nutrient concentration include ecosystem-level interactions among microbial activity, plant uptake, transport and landscape heterogeneities. Consequently, results of previous studies are mixed, probably reflecting different site conditions. For nutrient losses, high concentrations and high drainage water concentration followed an anomalous cold period (Mitchell *et al.*, 1996). In contrast, some studies reported that nutrient losses were not affected by, or even lower due to soil frost (Peltovuori & Soinne, 2005). In many laboratory incubations, both the surface and sub-surface soils were concurrently subjected to FTC, despite the slower responses of sub-surface soils to air temperature changes in the field, which could further exaggerate the effects of large amplitude FTC treatments (Henry, 2007). Also, there is insufficient field knowledge about how N concentration varies with respect to winter processes, particularly for circumstances under natural conditions of the frequency, duration and temperature of FTC. Despite the increasing recognition of the importance of FTC on nutrient environmental behaviour, there has been insufficient research investigating nutrient concentration variation in interflow.

Therefore, further mechanistic studies about nutrient concentration in interflow affected by winter processes have been required to improve the relative behaviour description, model establishment, and contaminant control.

In order to investigate the effects of winter processes, we carried out a series of experiments to study nutrient concentrations in interflow using a rainfall simulator in arable land and grassland. The main objective of this study was to develop a direct better understanding of the nutrient concentration in interflow affected by winter processes, as related to realistic soil temperature fluctuations.

## MATERIAL AND METHODS

### Site description

This study was carried out at Shenyang Agricultural University (Shenyang, China). Winters occur between November and April. January was the coldest month, with a mean temperature of –11.6°C (Fig. 1). An automatic weather station was installed at the experiment station. Soil temperature and water content sensors were also located at 1 and 20 cm depth. Data were recorded continuously at 1 hourly intervals.

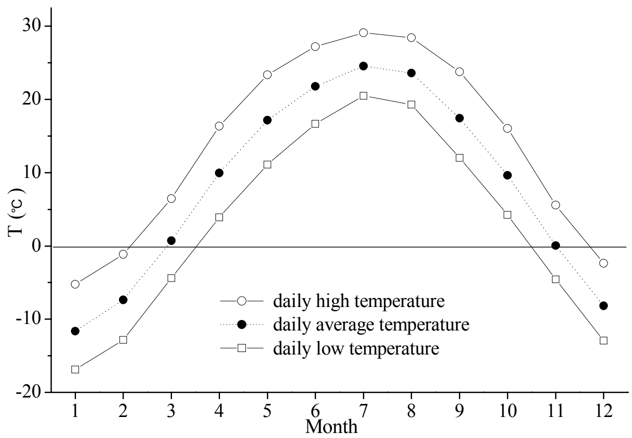


**Fig. 1** Monthly temperature in Shenyang.

### Rainfall simulation experiment and nutrient concentrations in interflow

Simulated rainfall studies were conducted within the arable land and grassland. A light weight rainfall simulator was used to study nutrient concentration affected by winter processes. A spraying nozzle was mounted on the manifold at a height of 1.5 m from the plot surface. The nozzle, associated plumbing, in-line filter, pressure gauge and electrical wiring were mounted on a 2 × 2 × 2 m wood frame fitted with a canvas windscreen. Local groundwater was used as the water source of the rainfall simulator, and had a total phosphorus (TP) concentration of <0.01 mg $L^{-1}$, total nitrogen (TN) of 0.02 mg $L^{-1}$, and pH of 6.3.

At the lower plot boundary, a metal flume (1 m length) was inserted laterally 2 cm into the soil to avoid the leakage of inflow and to permit sampling of the surface flow (Fig. 2). For interflow, two metal flumes (0.3 m length) were inserted 17 cm into the soil at 30 cm depth, which collected interflow but avoided soil disturbance. The water samples (surface runoff and interflow) were collected during the experimental period. Experiments on rainfall simulation were conducted in early November (before winter) and late April (after winter).

The water samples were immediately filtered (0.45 μm) and stored at ≤4°C before the samples were analysed for TN and TP. The water samples were digested with $K_2S_2O_8$-NaOH solution for TN and with $K_2S_2O_8$ before TP measurement. Phosphate-P in solution was determined colorimetrically by the formation of the blue phosphomolybdate complex following reduction with ascorbic acid. TN and TP were determined by UV-Vis spectrophotometer.

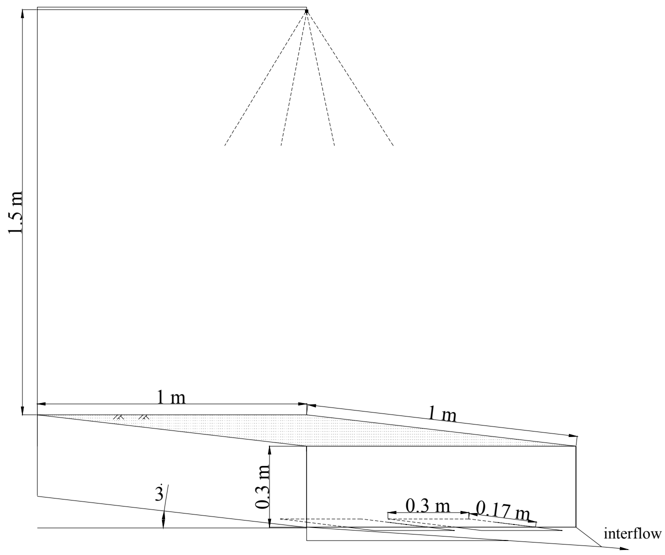


**Fig. 2** Nutrient concentration in interflow with rainfall simulator.

## RESULTS

In order to study the effects of winter on nutrient concentration, experiments with a rainfall simulator were conducted to investigate N and P concentration variation in interflow. Long-term overall winter processes not only affected chemical and physical properties of the soil, but also affected nutrient concentration. Concentrations of TN and TP were plotted against time for both arable land and grassland to evaluate the effects of winter on nutrient concentrations.

### Variation of TN concentration in interflow

Interflow is an important route of nutrient losses (Tang *et al.*, 2008). Interflow was investigated at 30 cm depth in this study. The result clearly demonstrated that TN concentration of interflow in arable land and grassland were affected by processes during winter. The N concentrations variation behaved similarly in the arable land and grassland. In the arable land plot, TN concentration increased about 5-fold after winter, i.e. from 20 ± 10 to 120 ± 10 mg $L^{-1}$ (Fig. 3(a)). Similarly, TN concentrations also increased for the grassland plot, i.e. from 35 ± 5 to 96 ± 38 mg $L^{-1}$ (Fig. 3(b)).

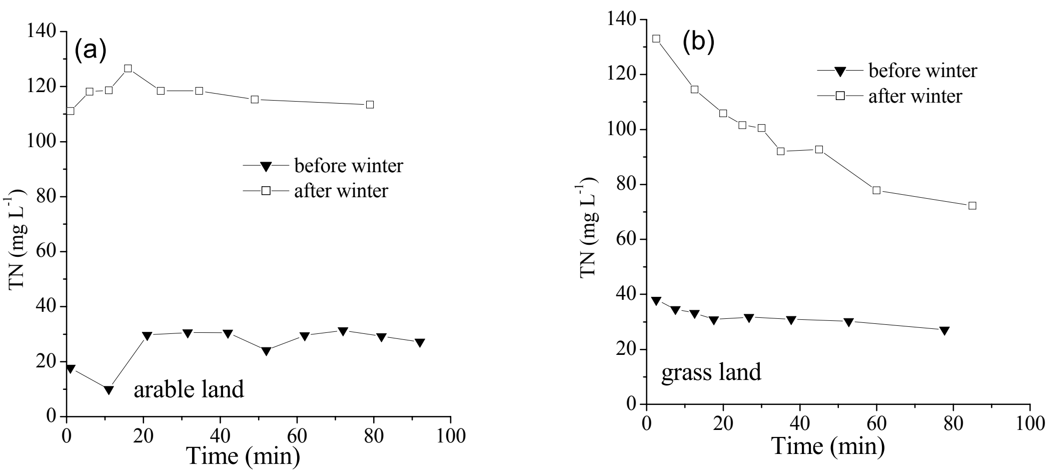


**Fig. 3** TN in interflow affected by winter processes in arable land (a) and grassland (b).

### Variation of TP concentration in interflow

The behaviour of P was different than that of N. Interflow TP concentrations are decreased after winter both in arable land and grassland, whereas TN concentrations increased. Arable-land TP concentrations decreased from 0.56 ± 0.16 to 0.16 ± 0.04 mg $L^{-1}$ after winter (Fig. 4(a)). Similarly, grassland TP concentration decreased from 0.22 ± 0.04 to 0.06 ± 0.04 mg $L^{-1}$ (Fig. 4(b)). TP concentrations in arable land were consistently higher than grassland, i.e. before and after winter.

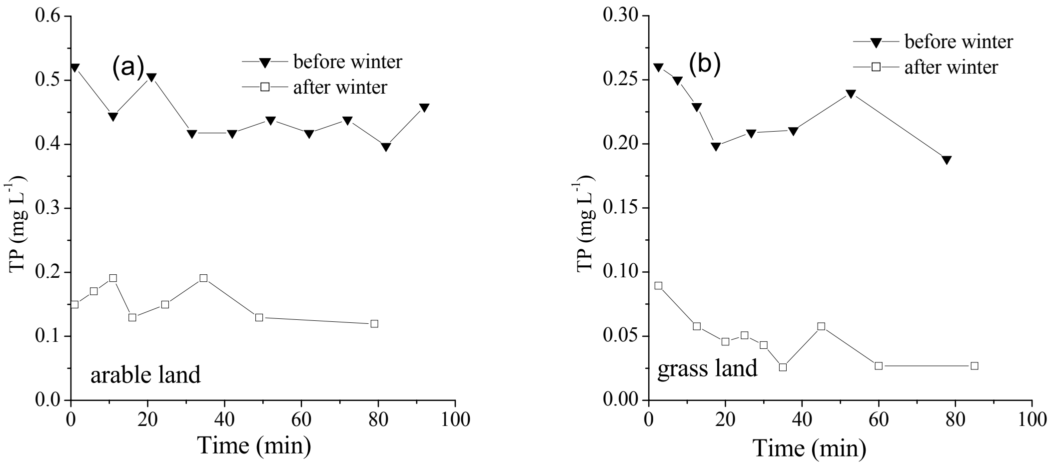


**Fig. 4** TP in interflow affected by winter processes in arable land (a), and grassland (b).

## DISCUSSION

In this study, higher N concentration was observed both in arable land and grassland in interflow after winter. In contrast, P concentration decreased after winter. These results suggested that there was a consistent variation in nutrient concentrations affected by winter processes between arable land and grassland. The environmental behaviour of NPS nutrients was impacted by the winter processes, which included nutrient accumulation and transformation, disruption of soil structure, and change of hydrological condition, etc.

### Nutrient accumulation and transformation

Due to soil freezing and runoff (which is generally low during winter), N and P accumulated in soil during the winter. For a mid-latitude site, which received high atmospheric deposition of N (ammonium and nitrate), isotopic tracers showed that most of the nitrate in upslope surficial soil waters after the onset of snowmelt originated from atmospheric sources (Sebestyen *et al.*, 2008). In addition, increasing mortality of fine-root and aboveground biomass during winter is another major nutrient source in soil (Fitzhugh *et al.*, 2001). The mineralization of organic matter in winter processes, induced more dissolved N and P in soil water (Herrmann & Witter, 2002; Roberson *et al.*, 2007). For the period after thawing, the rate of mineralization may increase (DeLuca *et al.*, 1992). TP significantly increased after FTC (Ron vaz *et al.*, 1994), which is consistent with our results.

Elevated overwinter mortality temporarily reduces fine-root length and plant uptake, thereby disrupting the temporal synchrony between nutrient availability and uptake (Fitzhugh *et al.*, 2001). Colder soils caused by shallow snow, induced surprising significant effects on root mortality, soil nitrate ($NO_3^-$) levels and hydrological fluxes of N and P in a mid-latitude site (Groffman *et al.*, 2001).

### Soil structure disruption

FTC occurred for two months in the experiment plots. The long-term FTC caused the disruption of soil structure, induced more microaggregates and decreased bulk density both in arable land and grassland (Table 1). These effects might play an important role in soil stability and soil sorption capacity. Similarly, soil water content increased during the winter (Table 1). In general, soil water content has shown to be inversely proportional to soil aggregate stability subjected to FTC (Layton *et al.*, 1993). Soil cohesion decreased markedly during winter and early spring months, and this change is attributed to pressures and associated shearing forces caused by FTC when water content was high (Kvaerno & Oygarden, 2006). Layton *et al.* (1993) also report that aggregation changes were largest when precipitation was high.

**Table 1** Values of physical and chemical properties in arable and grass land before and after winter, respectively.

| | Arable land[a] | | Arable land[b] | | Grassland[a] | | Grassland[b] | |
|---|---|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After | Before | After |
| Bulk density（$g/cm^3$） | 1.45 | 1.38 | 1.43 | 1.40 | 1.27 | 1.21 | 1.22 | 1.19 |
| Soil water content (%) | 18 | 31 | 23 | 31 | 18 | 31 | 23 | 31 |

[a] 0–5 cm; [b] 20–25 cm.

Macro-aggregate content decreased from 40% initially to 12% of total mass by the 15th FTC, while the micro-aggregate content increased from 19% to ~70% of total mass (Edwards, 1991). It is hypothesized that these effects caused the pollutant formerly adsorbed on soil aggregate surfaces to be released into soil water, which resulted in higher N concentration. However, the exposed new surfaces resulting from aggregate breakdown and collapse of continuous macropores, potentially increased pollutant adsorption on the soil aggregates. Due to the high adsorption capacity of dissolved P to these aggregates, it is hypothesized that these effects ultimately reduced the concentration of TP. Peltovuori & Soinne (2005) report that FTC did not increase TP leached from soils, and even decreased the TP concentration in the leachate. However, the increased solubility of soil P after FTC was also reported, which might be associated with more organic matter in soil (Ron vaz *et al.*, 1994).

## CONCLUSION

Long-term winter processes significantly impacted the concentration of N and P in interflow. Interflow N concentrations were higher after winter than before winter both in arable land and grassland. The concentration difference is attributed to N accumulation during winter, and N release (mineralization) from soil aggregates, which are affected by freeze–thaw cycles (FTC). In contrast, P concentrations decreased from before to after winter, which is attributed to the increased adsorption of P on exposed new surfaces created by FTC and the high adsorption capacity of the soil for dissolved P.

This study provides useful information for estimating nutrient concentrations in interflow affected by winter processes from arable land and grassland in mid-latitude climatic region. These results highlight the importance of NPS nutrient concentration impacted by winter processes. Study results suggest that interflow should be considered an important hydrological pathway of TN loss after winter.

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